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FOLIAR FERTILIZATION OF SOYBEANS DURING
THE SEED-FILLING PERIOD.

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Foliar fertilization of soybeans during

the seed-filling period

by

Ramon Garcia L.

A Dissertation Submitted to the

Graduate Faculty in Partial Fulfillment of

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I. INTRODUCTION

Foliar application of fertilizer macronutrients on field grain crops has not been advocated nor practiced extensively. Micronutrients including iron, zinc, manganese, boron, copper, and molybdenum are extensively applied to different crops in order to easily correct nutritional deficiencies. Foliar application of nitrogen has been successful when applied on horticultural and fruit crops in the form of an urea spray. For example, 80% of the total nitrogen applied to Hawaiian pineapple fields is applied to the foliage as urea sprays (Wittwer et al., 1963).

Numerous attempts to raise yields of soybeans above the average through soil fertilization have been made. The results have been limited and sometimes discouraging, especially under conditions that are average or above for soybean production. However, if obvious nutrient deficiencies exist, yields can be increased by appropriate fertilization and the response of the plant to such practice is similar to other crops as corn. Results from limited studies (Barel, 1975; Chesnin and and Shafer, 1953; Shumacher and Welch, 1970; Wittwer et al., 1963) of N and/or [illegible] foliar application on soybeans generally have not been encouraging.

No research, however, has been conducted to study the feasibility of foliar applications of balanced, complete nutrient solutions during the seed-filling period of soybeans and other grain crops.

Processes occurring in soybean plants that indicate a potential for foliar fertilization during the seed-filling period have been discussed by Hanway (1975). These processes can be summarized as follows: as seeds fill, these seeds become the dominant sink for carbohydrates being produced in the leaves. The soluble carbohydrate content of the stem and root decreases (Dunphy, 1972). Nodules stop fixing N, die, and slough off (Lawn and Brun, 1974). Root growth stops and uptake of some nutrients slows and stops. To supply the N, P, K, and S required by the developing seeds, these nutrients are translocated from the leaves and other vegetative plant parts to the seeds. This nutrient depletion of the leaves results in a decreasing rate of photosynthesis, and, in soybeans, the leaves turn yellow and fall off the plant. Applying nutrients to the leaves during this critical period could minimize this nutrient depletion of the leaves so photosynthesis could be maintained at a higher level which in turn would result in an increase in seed yields.

The studies reported in this thesis were conducted to determine:

1. The effect on soybean seed yields of foliar application of N, P, K, and S solutions during the seed-filling period.
2. The effect of different times of foliar application of an N, P, K, and S solution on soybean seed yields.

3. The response of 3 different soybean cultivars grown under reasonably optimum conditions, to a foliar application of an N, P, K, and S solution during the seed-filling period.
4. The effect of foliar application of nutrients on the nutritional content of leaves and beans, and the water soluble carbohydrate content of leaves and beans.
5. The effect of foliar fertilization during the seed-filling period on the seed size and other yield components.

II. LITERATURE REVIEW

A. Soybean Yields and Response to Fertilizers

Research conducted under a variety of experimental conditions showed that soybeans are less responsive to increased fertility than are corn and other crops (Caviness and Hardy, 1970; Miller et al., 1961; Peterson, 1961; and Pierre, 1944). In some cases the response of the soybeans to fertility differences was related to it. Barber (1967), and Melsted (1967) reported soybeans to be less responsive than corn to K or to fertilizer P differences, but equally responsive to soil P differences.

Pendleton (1968) studied extensively the r,sponsiveness of soybeans to fertility differences. He concluded that where soil test levels are low the response could be profitable, but where soil test levels are high the grower should not expect any response, and perhaps be looking first at other phases of his overall soybean production program. Generally, the fields with check yields above 2.690 ton/ha[1] showed only minimal response to fertilizers, while the fields with check yields below 2.690 ton/ha were more likely to respond.

Several authors have reported yield responses to fertilzers when check yields were 1.345 ton/ha or below (Carter and Hopper, 1942; Colwell, 1944; Kamprath and Miller, 1958;

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[1]From here on 1 ton = 1000 kilos.

Miller et al., 1961; Nelson et al., 1945). Several surveys have found high soybean yields to be associated with high fertility levels (Carter and Hopper, 1942; Kamprath and Miller, 1958; Metzger et al., 1925). There are some reports of yield responses to fertility differences and fertilizers when check yields were not low or when fertility levels were high (Pendleton, 1968; Vittum and Mulvey, 1944; Miller et al., 1961). There has been a great deal of speculation about the responsiveness of soybeans to fertilization. In spite of the enormous amount of research published, this has been predominantly empirical and little emphasis has been give to causal mechanisms (deMooy et al., 1973).

An important consideration about responsiveness of soybean to fertilizers is that the largest responses occur on the least fertile soils. Usually least fertile soils are associated with higher rainfall regions which in turn have larger yield responses from fertilization (deMooy et al., 1973). For example, large responses are reported from the Atlantic coastal states of the U.S. In North Carolina, Nelson (1946) reported yields being raised fivefold due to fertilization. In Mississippi, Anthony (1967) showed responses up to 1.480 ton/ha. A similar trend can be found in the Soviet Union, where deMooy et al. (1973) stated that there is response to fertilization in the humid eastern regions where increases in yield of 420 kg/ha are reported. However, in the chernozem areas where rainfall is limited the fertilizer response was smaller.

In the U.S.A., responses are variable and smaller in the more productive soils of the North Central Region. Lang and Miller (1942) concluded that in the north central U.S., soybeans do not respond to fertilization in the same manner as does corn. Working in Illinois, these authors reported that apart from K deficient soils the response of soybeans to fertilization was not profitable. Pierre (1944) confirmed in Iowa the results obtained in Illinois.

Under certain conditions and despite very low fertility levels, soybeans do not respond to fertilizers. Reports from the University of Illinois (1969) show that even increasing the level of P and K of the soil from 17 to 72 pp2m and from 250 to 949 pp2m, respectively, did not result in a significant response. Miller (1960) and Hanway and Weber (1971b) reported also a lack of response to P fertilization on a soil low in available P. Different reasons have been given to explain this behavior. deMooy et al. (1973) suggest that during periods of summer drought fertilizer nutrients incorporated into the surface soil tend to be unavailable to the roots. Also, these authors suggest that deficiency of elements other than those applied could cause a lack of response to P in a soil which is very low in P. For example, lack of response to P could be caused by a low K content of the soil.

In order to obtain more consistent results some authors tried more nutrient factors which were varied simultaneously (Miller, 1960; deMooy, 1965; Walker and Long, 1966). Others (deMooy and Pesek, 1971) tried high rates of fertilization (448 and 896 kg/ha of P and K). Yield depression that was observed from P application on a soil testing low in P and K turned into a positive response at a very high rate of K application. These kinds of results show that yield response curves for soybeans, which show small but consistent response to P and K, may reach a maximum at unexpectedly high rates.

B. Rate of Uptake, Nutrient Composition and Translocation of Elements Within the Plant

Hanway and Weber (1971b) measured the amount of N, P and K in the various parts of the plant at 10 stages of development. They found a linear rate of nutrient uptake between full bloom and "green bean" stage. Their data show also increasing rates of uptake prior to full bloom. However, after the "green bean" stage, the nutrient uptake rate decreased to 0. These authors (Hanway and Weber, 1971a, d) showed average accumulation rates of 4.5, 0.4, and 1.5 kg/ha/day of N, P and K for the whole plant during the period of full bloom to seed filling. During the same period, total dry weight increased 167 kg/ha daily. The rate of nutrient accumulation was slow in early stages followed by a rapid increase at the beginning of flowering. After flowering, and until senescence, nutrient uptake continued at a relatively constant rate.

Harper (1971) reported that NO_3^- showed a peak in uptake during pod set and early seed filling. He also observed that

P and K showed a peak between full bloom and midpod fill. deMooy et al. (1973) stated the rate of nutrient accumulation relative to that of dry matter has a bearing on nutrient needs at various stages of development of the plant. When the nutrient and dry matter data from Hanway and Weber (1971b) is superimposed, it shows little difference in accumulation rate through the season, except during bloom when the absorption of N and P lagged behind dry matter accumulation. These authors showed that 40% of the N, 45% of the P and 40% of the K are absorbed after the beginning of bean formation.

deMooy et al. (1973) stated that nutrient absorption is rapid in relation to dry matter production during early stages. As a consequence of this, the nutrient concentrations are high at these stages. Later, due to the rate of accumulation of dry matter and to the translocation of nutrients to developing seeds, the nutrient concentration of the various tissues generally decreases.

Hanway and Weber (1971d) reported increasing P and K contents in the leaves, petioles and stems until the three-leaved stage. After this stage these authors showed that the nutrient concentration steadily declined in all parts.

Data from several authors (Hanway and Thompson, 1967; Hanway and Weber, 1971a,b,c,d; Harper, 1971; Henderson and Kamprath, 1970; Hammond et al., 1951) showed that N, P, K, Ca and Mg concentrations in the total plant tended to decrease throughout the season until the last weeks. During the last few weeks, the contents changed very little if fallen leaves were accounted for.

The data of Hanway and Weber (1971c) confirmed the facts that cultivars differed little in composition, N content at stage R7 was between 5 to 6% in leaves, 4% in pods, 2.5 to 3.5% in stems, and 2 to 3% in petioles. At stage R 7.0 the N content was 6.5% in seeds, 2% in leaves, 0.9% in pods, 0.7% in peioles and 0.6% in stems. Henderson and Kamprath (1970) reported a downward trend in the vegetative parts from 3.6% N at 40 days to 1.0% N at 140 days after planting. On the other hand, the N content of the seeds and pods increased from 3.8% in the beginning to 4.8% at maturity.

The data shown in the preceding paragraphs supports the concept that late in the growing season there is an active translocation of nutrients from the vegetative tissues into the forming seeds. This phenomenon leads to the depletion of nutrient from the leaves, which in turn cannot carry on photosynthesis and therefore senescence occurs.

Photosynthate is also translocated to the regions of energy utilization, or sinks, which include the roots (Thrower 1962, 1965), apex, floral buds, seed and leaves (Winter and Martimer, 1967). It seems that before flowering, the photosynthate is translocated from mature leaves to roots, new leaves, and the apical meristem (Aronoff, 1955; Belikov, 1955a, b, 1958; Belikov and Pirskii, 1966). The recipient of the photosynthate is determined by the distance between the source and potential recipient (Belikov, 1955a, 1957b; Belikov and Pirskii, 1966; Crafts, 1967).

Two distinct patterns of translocation of labelled assimilates appear to exist in soybeans (Thaine et al., 1959; Bloomquist and Kust, 1971). Before pod filling, translocation from a given leaf occurs to meristematic areas above the leaf. As the leaf ages and its position changes relative to the stem apex, more and more of its exports are directed downwards. Most of the assimilates going into the roots come from lower leaves on the plant. After pod filling starts, translocation from a given leaf occurs primarily to the pods in the axil of that leaf and at the second node below that leaf (Bloomquist and Kust, 1971). Only very small amounts of label have been recovered from the roots and nodules after pod filling (Hume and Criswell, 1972).

Several authors (Aronoff, 1955; Belikov, 1957a; Crafts, 1967; Hicks and Pendleton, 1969; Koller, 1971) have proposed that photosynthate sinks exert a demand for photosynthate and that the magnitude of the demand decreases with distance from the source. Belikov (1957a, b) concluded that the demand by seeds for photosynthate must be greater than the amount normally supplied. Products of photosynthates also provide energy for the nodules. It has been shown by Lawn and Brun (1974) that symbiotic nitrogen fixation in soybeans declined during pod filling as the result of inadequate assimilate supply to the nodules.

Thibodeau and Jaworski (1975) suggested that there is a close and competitive relationship between the process of nitrate reduction and nitrogen fixation, with the latter process dominating as the major source of fixed nitrogen after the plants have flowered and initiated pods. The rapid decay of nitrogen fixation at the time of midpod fill suggests a competition between roots (nodules) and pods for available photosynthate. This competition appears to lead to the breakdown of foliar proteins and senescence (Thibodeau and Jaworski, 1975).

C. Feasibility of Foliar Fertilization

Foliar application of certain nutrients has been a commercial agricultural practice for a long time. Nutrients applied usually involved micronutrients, and as early as 1844 Gris discovered that a chlorotic condition observed in plants on calcareous soils could be overcome by applying solutions of iron salts to the leaves. Nitrogen has been the macronutrient most widely used and the one that shows the greatest success achieved. For example, 80% of the total nitrogen applied to Hawaiian pineapple fields is applied as a foliar spray of urea (Wittwer et al., 1963). Several reviews on this subject have been written in the last 15 years. Tukey et al. (1956, 1971), Biddulph (1960), Wittwer (1964), and Wittwer et al. (1965) all agree on the feasibility of foliar fertilization with N and P under different conditions and on a variety of crops.

A great amount of research on the subject has been carried on in Europe. This has been summarized by Burghardt (1961), Ferencz (1963) and Beeftink et al. (1957).

Kick and Hellwig (1959), cited by Barel (1975), reported that sunflowers could be completely supplied with nitrogen, phosphorus and potassium through foliar application. Burr et al. (1956) determined that the total amount of P which sugar cane required could be supplied by foliar sprays of KH_2PO_4. Wittwer (1951) observed that foliar fertilization would likely have its greatest possibility as a means of supplementing the supply of nutrients normally absorbed by the roots.

With the availability of radioactive tracers more than 30 years ago, a great interest developed to study foliar absorption of mineral nutrients. This led to the determination of accurate pathways of uptake and translocation as well as a means of distinguishing between nutrients absorbed simultaneously by the leaves and the roots.

D. Pathways of Absorption and Translocation of Foliar Sprays

The process of absorption of nutrients by the leaves takes place in several steps. Franke (1967) pointed out that this process occurs in 3 steps. In the first step the solution applied on the leaves penetrates the cuticle and cellulose wall via free diffusion.

After the solution has penetrated the free space, in a second step it is absorbed to the surface of the plasma membrane by some form of binding. In the third step the absorbed substances are taken up into the cytoplasm in a process which requires metabolically derived energy.

The cuticle seems to be the major obstacle for the penetration of substances applied on the leaves. Some absorption can take place through the stomatal pores; however, this has only the effect that solutions enter into the stomatal chambers and intercellular spaces and not the cells themselves. The outer walls of cells lining these cavities are also covered by an internal cuticle so the problem still persists and is only shifted from the outer to the inner surface of the leaves (Franke, 1967). On the other hand, Boynton (1954) showed that the uptake probably occurs through both cuticle and stomata.

Wittwer et al. (1965) demonstrated that diffusion through cuticular membranes is relatively rapid and that cations penetrate them more readily than anions. Comparing the rate of absorption of urea with that of cations, urea exceeds it by 10- to 20-fold (Wittwer et al., 1965). This may explain in part why urea is so effective as a nutrient spray for nitrogen. Yamada et al. (1965) showed that the rate of absorption of urea through cuticular membranes increases with time.

After the cuticular membrane is crossed, solutes may be either absorbed directly by leaf cells or transported by diffusion within a free space volume. It is important to point out that some absorption takes place near the base of the leaf hairs, which have thinner cell walls or less cuticularization in that area (Linskens et al., 1965).

The cell wall constitutes the second barrier that the solution finds on its way. The cell wall is penetrated by a multitude of small strands named ectodesmata. Plasmodesmata, in turn, interconnect all living cells making the protoplasm of the entire plant an organic whole. Many of the ectodesmata penetrate the outer wall of the epidermis and terminate beneath the cuticle. Franke (1967) suggested that the location and frequency of these ectodesmata are related to the phenomenon of foliar absorption. He also showed that the epidermal cells and stomatal guard cells are consistently equipped with the greatest number of ectodesmata, and that turgid leaves contain more ectodesmata than wilted ones, and the number is much greater during the night and early morning than during daytime.

Linskens et al. (1965) suggested that foliar absorption is favored where stomata occur in large numbers. It is important to point out that ectodesmata occur regularly and in large numbers in and around the stomatal guard cells.

The third barrier that the solutes applied to the surface of leaves find in their way is the plasma membrane which is semipermeable. The penetration of other compounds different than water is the subject of many theories which are not fully developed. Depending upon the nature of the molecule it would become more or less difficult to gain entry to the living symplast (Franke, 1967).

The overall mechanism of foliar penetration could be summarized as follows. The cuticle is penetrated mainly via intermolecular spaces and the movement of ions and organic compounds occurs by diffusion. Cations penetrate the cuticle more rapidly through intermolecular spaces of cutin than do anions, which are hampered by the negative charges of the cuticle. Nonpolar undissociated molecules as urea, enter even more readily than cations. Yamada et al. (1965) showed that urea penetrates the cuticular membrane with a velocity higher than one would expect from simple diffusion. They also showed that the extent of the penetration of urea exceeds that of ions by 10- to 20-fold and is independent of the concentration and that urea favors foliar absorption of ions such as phosphate when are applied together (Yamada et al., 1964b). One possible explanation of this effect is that certain loosening of the membrane structure might occur by charging ester, ether, and diether bonds (Yamada et al., 1964a). Bukovac and Wittwer (1961) also agree that the mechanism of penetration must be diffusion. They suggest different paths for lipophillic substances and for the hydrophillic solutes (Okuda and Yamada, 1962). The most important step of absorption is the incorporation of the penetrating substances into the protoplast. This occurs principally along the surface of the plasma membrane and it is an energy-requiring process and depends on the metabolic processes (Franke, 1967). Ahlgren and Sudia (1967) determined that phosphate uptake by leaves is an active process and is energy dependent and that the greater absorption by immature leaves was not due to fewer barriers but was metabolically controlled and had energy requirement. They also confirmed the fact that light increases phosphate uptake.

Several theories (Franke, 1967) have been proposed about the mechanism of active absorption, such as the carrier theory, change of permeability and pinocytosis (Laties, 1959; Fried and Shapiro, 1961). Once the compounds are absorbed they are translocated to other areas of the leaves or to other plant parts via plasmodesmata (symplast and phloem). The rates of uptake and translocation of the applied compounds are variable for different nutrients and species. A great amount of research on this subject has been done with P. Burr (1962) working with sugar cane measured 50% absorption of the applied phosphorus from KH_2PO_4 within 15 days. Thorne (1958) with French bean, determined the rate of uptake of P^{32} from labeled NaH_2PO_4. The uptake was rapid during the first few hours and fell to zero after 4 days. He detected P^{32} in the roots after 3 hours and it continued to move out of the leaves for 6 days after the application.

Wittwer et al. (1963) listed the time required for 50% absorption of nitrogen as 1 to 6 hours for citrus, apple, pineapple, banana, beans, tomatoes and corn. This time was more than 24 hours for sugar cane, tobacco, celery and potatoes.

The time required for 50% absorption of P is usually longer. Apple, beans, and sugar cane recorded times between 7 to 15 days. Barel (1975) determined that 67% of the applied P as tripolyphosphate was absorbed within 10 days, and 87% of the absorbed P was translocated outside of the leaves within the same period. He also determined that the rapid intake of orthophosphate was suspected to be an important reason for the damage of the leaves observed in corn and soybeans. In the case of K, Ca, S and Cl, the time is between 1 to 4 days for apples and beans and 8 days for S.

Micronutrients require less than 24 hours with the exception of Mn that requires 48 hours.

Barinov (1959) cited by Barel (1975) determined that the movement of Ca^{45} was 1.3 to 2 times less than the movement of P^{32}. Both nutrients moved upward and downward and may be translocated to the roots. Uturgauri and Oniani (1963) found P^{32} in the roots of tea and corn plants within 24 hours after the nutrient was sprayed on the leaves. Working with soybeans Barrier and Loomis (1957) found that 34% of the P absorbed by the leaves was translocated after 2 hours. They also determined that 80% of the P was present in organic forms after 24 hours. The translocation of the applied P was slowed by depletion of leaf carbohydrates. After supplying the leaves with $C^{14}O_2$ radioactive photosynthate may move out within minutes. This suggests that chemical transformation is required before P^{32} can be translocated.

Moustafa et al. (1971) found that the translocation of P^{32} applied on soybean leaves into root nodules was excellent. They reported 90% of the P^{32} localized in the soluble part of the plant tissues of the nodules and 50% was in ATP, ADP and AMP.

E. Sources of Nutrients Used in Foliar Fertilization

Urea is the most widely used N source in foliar fertilization. It is used singly and in combination with many formulated mixtures. Due to its nonpolar nature the uptake is rapid, and it is highly mobile through the plant. Wittwer (1964) listed tolerances of plant foliage to urea sprays diluted in 100 gallons of water. Some crops seem to be very tolerant as wheat and bromegrass (up to 800 lb/100 gallons). In general, crops like sugar cane, pineapple and orchards can resist up to 20 lb/100 gal. The same concentration is listed for potatoes, sugar beets, tobacco and corn. With the exception of carrots, celery and onions, vegetable crops do not tolerate more than 6 lb/100 gal. Concentrations vary greatly with plant type, species and other factors as the time of application. The values given by Wittwer (1964) correspond to maximum tolerances early in the growing season, probably these would change when other time of spraying is used. $NaNO_3$ and KNO_3 have also been used as a source of N with contradictory results.

Barel (1975) tried different compounds which contain phosphorus-nitrogen bonds and phosphorus-nitrogen-phosphorus linkages. The nitrogen was present in the amide or imide form. He tried different condensed phosphates and phosphorus-nitrogen compounds. Nearly all phosphorus compounds which he investigated were applied in the ammonium form.

The condensed phosphates and phosphorus-nitrogen compounds proved by Barel (1975) to be most promising compounds for foliar P application when compared with orthophosphates and other inorganic sources of P. Tripolyphosphate was the best condensed phosphate on corn, 67% of the applied phosphorus was absorbed within ten days, and 87% of the absorbed phosphorus was translocated within the same period. Tetrapolyphosphate followed closely as the second best compound. Barel (1975) stated that these compounds could be applied as 2.5 to 3 times the quantity of P that could be applied as orthophosphate. He showed that soybeans could tolerate only 2/3 to 3/4 of the quantities that could be applied to corn. The only exception was phosphonitrilic hexaamide, which in the case of soybeans could be applied at a higher concentration than corn. Barel (1975) also tried some ring compounds as a source of P. He found that tri- and tetrametaphosphate could be applied to corn 3 to 4 times that of orthophosphate, but the rate of absorption was much less than that of the polyphosphates. Barel (1975) also tried 3 different urea phosphates but even though they were absorbed well they produced more damage to the leaves than regular condensed phosphate. The same situation occurred when he tried several organic phosphates (creatin phosphate, glucose-6-phosphate, fructose-1,6-diphosphate, and adenosine phosphate among others). None of them were superior to the condensed phosphate.

In relation to applying K and other nutrients the soluble salt of each nutrient element appears equally effective as foliar sprays. Chelates have been used as special formulations for some nutrients, but there are doubts about their usefulness when compared to the inorganic salt. Cook and Mitchell (1958) found that chelated zinc preparations were no better than inorganic sources for grapes. Lingle and Holmberg (1956) found that $ZnSO_4$ was more effective than the chelated form for vegetables. Haertl (1955) suggested that the type of foliage influenced the reaction of leaves to chelates. Firm and thick leaves often respond favorably; on the other hand, plants with soft and succulent foliage respond negatively.

F. Factors Affecting the Foliar Absorption of Nutrients

Several factors affect the absorption of nutrients by the leaves. Some of these factors depend on the plant itself, such as the stage of development of the plant, age of the leaf, leaf thickness, leaf surface and differences between cultivars and plant species. Other factors are environmental, like air humidity, temperature, pH of the solution applied, and addition of sugars, and surfactants (Tukey et al., 1956). Leaves are one of the most important variables in nutrient absorption. Wittwer and Lundahl (1951) established in 1951 that young expanding leaves showed greater nutrient absorption than full grown leaves. Vogl (1960) cited by Barel (1975), and Fisher and Walker (1955) also found that young leaves of vegetables and apples showed higher rates of absorption than older leaves.

Bukovac and Davidson (1961) attributed the limited absorption of foliar applications of P^{32} to the extremely thick cuticular layer and the form of the needle-like leaves of Toxus cuspidata.

It has been found (Burr et al., 1956; Ursulenko, 1958; Kaindl, 1954) that there is a greater penetration of pesticides and nutrients through the lower leaf surfaces than through upper surfaces. The reason for this is that in most plant species the surface of the lower leaves shows a thinner cuticle and greater number of stomata when compared to the upper surface of the leaves.

Several authors have concluded that the absorption of nutrients and specifically P by leaves is an active process, which is metabolically controlled and requires energy and that the overall process of foliar absorption is coupled with plant metabolism (Yung and Wittwer, 1963). Srinivasan (1961) working with beans measured a maximum distribution of absorbed P^{32} when the plants were exposed to unfiltered light; this occurred when the plants were kept in darkness. Ahlgren and

Sudia (1967) concluded that the greater absorption of P^{32} by immature leaves is not due to fewer barriers, but is metabolically controlled and has an energy requirement. Teubner et al. (1957) showed that the absorption of nutrients by leaves is generally greatest during daylight. A favorable water balance within the plant is an important factor that affects foliar absorption of nutrients and translocation. Van Overbeek and Bloudeau (1954) stated that the swelling of the polar cutin due to water supply spreads the wax components farther apart and thereby enhances the permeability of the cuticle to water and water-soluble solutes. Pallas and Williams (1962) found that more P^{32} was absorbed when the plants were not under moisture stress. They also determined that 8 times as much was translocated below 1/3 atmosphere moisture tension as at 3 atmospheres.

The addition of sugars to the foliar sprays has been used as a practice to avoid leaf burning due to urea and orthophosphates and to enhance absorption of the nutrients applied. Yatazawa and Higashimo (1953) determined that a 5% solution of fructose, sucrose and glucose increased the P absorption by wheat plants by threefold. The reason for this is the formation of phosphate esters in the presence of inorganic phosphate. On the other hand, Teübner et al. (1957) determined that additions of sucrose with the foliar sprays reduced the absorption but enhanced the transport of nutrients from leaves in plants which were low in sugar.

Barel (1975) suggested that the beneficial effect on absorption and decreasing leaf burn of the addition of urea to a solution containing phosphates was probably due to the bonding of urea and phosphoric acid. This bonding might aid in penetration of the phosphoric acid into leaves. He also suggested that the action of urease inside plant cells should hydrolyze the urea to ammonium, which in turn would neutralize the phosphoric acid. The addition of sucrose to urea solutions has been found to be beneficial due to the decreasing effect on leaf burn. Barel (1975) suggested that it seems reasonable that the sucrose forms a syrup as the water evaporates and prevents the urea from attaining a toxic concentration. Ellerton and Dunlop (1966) found that urea forms a urea-urea and urea-sucrose dimers in solution, which in turn reduce the toxicity due to the effect of solutes in increasing the solute suction of the solution on the leaves. Also urea and sucrose produce neutral solutions and neither sucrose nor urea is ionic. Unpublished work in the Agronomy Department at Iowa State University conducted by Dr. P. K. Hanley showed that inclusion of sucrose in a urea and phosphate solution applied to soybean leaves reduced significantly the leaf damage resulting from application of urea and phosphorus. Additions of other substances have been reported to affect the absorption of nutrients by the leaves. Boroughs and Labarca (1961) reported that additions to the leaf surface of pepsin, trypsin and pectinase increased the foliar absorption of P^{32} by leaves of *Phaseolus vulgaris*. Kovalik (1969) showed that additions of 0.001% Heterauxin or 2-4D to an NPK foliar spray increased the yield of tomatoes when compared to NPK alone.

The pH of the solution has an effect on the rate of absorption and translocation of the P applied as different salts. Yeh (1967) determined that the rate of P absorption was greater at pH 3 or 4 regardless of the source of P. Chu and Ku (1966) found that the amount of $P^{32}O_4$ that remained on rice leaves increased with the pH values of the different solutions tested. Cardoso and Boroughs (1960) showed that higher values of absorption and translocation of P occurred at pH 5 and 6 and very low values at pH 7. Bester and Meynhardt (1968) reported that orthophosphoric acid was more readily absorbed by grape leaves when the pH of the solution was adjusted to 2.5 with potassium hydroxide than from a solution at pH 3.5 or pH 5.0. De Datta and Moomaw (1965) found that when a solution of potassium pyrophosphate at pH 11.2 was applied to sugar cane, it caused severe damage to the plants. No damage was observed when spraying the same solution at pH 5.3 which was adjusted with HNO_3. Phosphate uptake was also affected by the accompanying cation. Boroughs and Labarca (1962) applied different phosphates of ammonium, sodium and potassium. They found that absorption and translocation of P was greatest with ammonium and the least with potassium. Teubner et al. (1957) and Roldan et al. (1968) confirmed these results.

Certain studies on the effect of temperature on the mineral nutrition of plants suggest a relationship between these two variables. Shtrausberg (1958) stated that nutrition by foliar application would be more efficient than nutrition through the roots at low soil temperatures. He suggested that uptake by leaves occurs more readily than by roots under these conditions. A decrease in soil temperature from 19 to $6^{o}C$ reduced the assimilation of P by half. This same reduction of air temperature did not produce any effect on P assimilation. The foliar applications of phosphorus were more efficient than doubling the dose of P added to the soil at $7^{o}C$ (Zhurbitzky and Shtrausberg, 1958). Furthermore, several authors have reported that due to temperature effects, slowest drying and dew formation, spraying in the evenings gave the best results (Koontz and Biddulph, 1957).

Klechkowski (1956) speculated that foliar fertilization could be used as a tool to extend the northern boundaries of successful crop production. He stated that the limiting growth factor may well be the inability of the plant root to take up nutrients from a colder soil.

G. Response of Different Crops to Foliar Fertilization

The literature on this subject is scarce and sometimes contradictory. An attempt to summarize the work done on different crops is in the following sections.

1. Wheat and small grains

Combined sprays of urea and superphosphate on wheat produced an increase in yield of 14% as reported by Narayanan and Vasudevan (1957) in Russia. Davidescu and Davidescu (1960a) sprayed with a 1% solution of NH_4NO_3 and superphosphate between tillering and ear formation and then followed with a 3% solution of NPK. After 5 sprays they reported an increase in yield of grain and straw and greater numbers of fertile ears and seeds per ear.

As a result of a combined spray of P and K on wheat in the spring, the yield was increased by 38% as reported by Chumakov and Bystrova (1958). Ferencz (1954) cited by Barel (1975) showed a small increase in wheat yield after several sprays of a 5% superphosphate solution. Rozhanovskii (1956) cited by Barel (1975) reported an increase in yield of wheat up to 1.53 ton/ha after spraying with superphosphate solution at blooming stage. Suleimanov (1956) cited by Barel (1975) showed a 12% increase in yield after spraying wheat growing on podzolic soils.

Asbour and Saleh (1973) applied urea on wheat. A treatment that consisted of a 1% solution increased the number of spikes per plant and produced the highest yield. Foliar application of urea also produced taller plants and more tillers. Working with different times of foliar application of urea on wheat, Jain and Agarwal (1973) determined that two sprays at 30 and 35 days after planting gave higher yields than did sprays applied at earlier growth stages.

Urea applied as foliar spray has been shown to interact with water stress. Alexander (1973) showed that with foliar application of urea and K, the grain production of wheat was less affected by water stress under rain-fed conditions. Comparing urea with NH_4NO_3, Vertil and Malyuga (1970) determined that the two forms were equally effective in increasing accumulation of glutin, protein, tryptophane, and phosphorus, and in improving the fractional composition of the protein. They tried urea solutions up to 40% without showing any sign of damage. Mathus et al. (1969) showed a 2% solution of urea spray containing 11.2 kg/ha of N increased grain and straw yields. This increase was not greater than the increase from the same amount of nitrogen applied to the soil. The same kind of results were reported by Nerson and Karchi (1972). De (1971) reported increases in wheat yield, up to 60%, due to spraying a solution of 10 or 20% urea at a rate of 36 l/ha.

Foliar sprays with microelements have also been reported to increase wheat yield, protein percentage of the grain and shoot weight (Asbour and Hegazi, 1972).

Working with oats, Von Boguslawski and Vomel (1957) obtained increases in oat yield as a result of spraying with an NPK solution. Several authors showed significant yield increases of barley due to foliar spray using urea in concentrations up to 20% as a source of N (Bezdek and Flasarova, 1973; Vonka and Bezdek, 1974; Singh and Bains, 1973). Spraying with a solution with 20% urea at a rate 39 l/ha, Chanham et al. (1971) showed an increase in yield of rice up to 15% (34.5 kg grain/kg applied N). Equivalent figures for experiments with wheat were 23.5% at a rate 73 l/ha and 31%. Bhaskaran and De (1971) applied 100 kg/ha of N to rice; 20% was applied as foliar spray (3% urea solution) or as top-dressing. The highest yield was a result of the foliar spray treatment.

2, <u>Corn</u>

Very little research in foliar fertilization of corn has been conducted and usually only one or two nutrients have been tested. Narayanan and Vasudevan (1959) reported an 18% increase of the weight of maize cobs after spraying the plants with superphosphate solution. Corn is known to absorb to a greater extent the P applied to the leaves when no N or K is applied to the soil (Pavlov and Ivanov, 1960). Thomas (1960) showed an increase of dry matter of corn after foliar application of monobasic potassium phosphate, calcium phosphate or ammonium phosphate. Singh and Sarolia (1970) obtained significant increases in yield (29%) and N uptake (44%) after spraying with urea at a rate of 60 kg/ha. The crop was sprayed 3 times during the growing season; at first irrigation, knee high stage and tasseling. Barel (1975) sprayed several condensed phosphates in a field experiment, and obtained an increase in yield statistically significant when compared with the check. The yields with tripoly- and tetrapolyphosphate were 760 and 754 kg/ha above the control yield of 10.23 ton/ha. He sprayed the plants 3 times: the first spray was applied when the plants were about 2 feet tall, the second just before tasseling and the third after silking. The total amount of P applied for any treatment was 28 kg P/ha. Barel (1975) proved under greenhouse conditions that corn plants can be grown to maturity when all the P they require was supplied by sprays and was not absorbed by roots.

3. <u>Soybeans, sunflowers and cotton</u>

Barel (1975) tried different condensed phosphates applied as foliar sprays on soybeans in a field experiment. He reported an increase in yield (significant at the 18% level) of 256 kg/ha when the check plot was compared with the treatment that received 28 kg/ha of P as ammonium tripolyphosphate. In another experiment, Barel (1975) determined the maximum concentration of P as condensed phosphates that could be applied to soybean plants in the greenhouse. Also the response of plants to spraying with these P compounds was investigated. The yields of plants sprayed with the different P compounds significantly exceeded the yields of the unsprayed control with all P sources except tripolyphosphate. Sprays with tripolyphosphate produced considerable leaf damage, which was reflected in the weight of 100 seeds. Barel (1975) determined that soybean plants growing in the greenhouse can be grown to maturity when all the P they need was supplied by sprays.

Shukla (1974) reported that a foliar application of 15 or 30 kg/ha of P to soybeans produced a higher yield than the same quantities applied in the soil. On an acid clay soil, only foliar application of P increased the yield significantly. The protein content of the grain was increased due to the foliar P fertilization.

Belikov and Thatschenko (1961) cited by Barel (1975) and Belikov and Burtseva (1966, 1967) cited by Barel (1975) applied a 2% superphosphate solution on the leaves at the rate of 2 kg P/ha at the end of flowering. They reported that soybeans absorbed the P^{32} from superphosphate that was sprayed. They also found an increase in yield of 15 to 20% and an increase in total oil production of 16%.

Working with sunflowers, Galgoczi (1967) cited by Barel (1975) reported an increase in yield of 62 and 97% when the crop was sprayed one or two times with an NPK solution.

Bhoj et al. (1969) sprayed cotton twice with a 0.2% solution of KH_2PO_4 in the greenhouse and obtained a significant increase in yield. Verma and Sahni (1963) reported similar results. Ferraz et al. (1969) showed that a urea solution up to 15% could be applied at a rate of 45 l/ha on cotton without damaging the leaves.

4. Other crops and vegetables

Davidescu and Davidescu (1960b) sprayed tomatoes three times late in the season with a solution of 5% nitrogen (NH_4NO_3), 1% phosphorus (super phosphate), 1.0% potassium (K_2SO_4) and .01% boron. They recorded an increase of yield up to 17%. Mel'nichuk (1960) cited by Barel (1975) obtained yield increases from 30 to 39% after using foliar sprays composed of NP, NK and PK solutions. NPK solutions increased yields up to 48%. On the other hand, Mostert and Sonneveld (1964) showed that when tomato plants were adequately supplied with NPK in the soil there was not a yield increase to foliar application of NPK. Bottini and Morra de Lavriano (1958) reported that tomato growth was more than doubled by sprays of .06% of $(NH_4)_2PO_4$ applied twice weekly totalling 15 times.

Kuthy (1954) sprayed lettuce seedlings with a 3 to 4% NPK solution and obtained a yield increase within 10 days. The production and protein yields of peas were increased with PK sprays applied at flowering. Khodzhaeva (1961a, 1961b) cited by Barel (1975) obtained the highest yield increases (up to 20%) after spraying strawberries with a NPK solution. He reported that four-year-old plants responded more than two-year-old plants and that fall spraying increased the number of berries and spring spraying increased the berry size.

In apples Ursulenko (1958) obtained an increase in production of 32% due to an increase of photosynthesis during the first 10 to 15 days after foliar sprays with P and K. McNall and Hinckley (1973) sprayed almonds with zinc, manganese and phosphorus. They reported an increase of 19% in yield over a 4-year period. Aliev (1967) sprayed grapes with a NPK solution and showed an increase in yield and sugar content of the berries. He also reported an acceleration of the ripening.

Natali and Zucconi (1968) showed an increase of fruit yield of grapes by 22% after spraying 5 to 9 times with urea, phosphoric acid and potassium sulfate. This was in combination with NPK applied to the soil. Pecznik and Merei (1962) cited by Barel (1975) also working with grapes reported increases of yields up to 33% after spraying with a 2% superphosphate solution.

There are reports of yield increase due to complete foliar fertilization in coffee, cacao, peach, pear and orange (Ananth, 1961; Carne, 1966; Madero Bernal, 1953; Sato et al., 1954; Eggert et al., 1952).

Sugar beets seem to respond well to foliar fertilization. Nagymihaly et al. (1954) cited by Barel (1975) reported that spraying with a 3% NPK solution late in June and early July increased the fresh weight of roots by up to 31% and the yield of sugar by up to 40%. Thorne (1955b) also showed an increase in yield and sugar due to spraying with a NPK solution. Including N in the solution enhanced the absorption of P and K from the soil. Milica (1959) sprayed sugar beets with a NPK solution 3 to 4 weeks before harvest. He recorded an increase in root yield and sugar production of 26 and 35%, respectively.

III. EFFECT OF FOLIAR FERTILIZATION WITH UREA, POLYPHOSPHATE AND SULFATE AT DIFFERENT TIMES OF DEVELOPMENT, 1974 EXPERIMENT

A. Materials and Methods

The field experiment in 1974 was conducted to study the effects of foliar applications of different materials at different times during the seed-filling period.

The experiment was planted on June 6 at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames on land in a soybean-corn crop sequence.

The soils in the experimental area are classified as a Webster-Nicollet complex. The slopes are nearly plane to slightly concave (0 to 1%). Webster soils (Typic Haplaquoll) are poorly drained with moderate permeability. Nicollet soils (Aquic Hapludoll) are somewhat poorly drained with moderate permeability. A uniform application of phosphorus and potassium fertilizer was applied at a rate of 200 and 100 kg/ha, respectively, over the whole experimental area. The corn preceding the soybeans was fertilized with 200 kg nitrogen/ha, using urea as a source. Hawkeye cultivar was planted at the rate of 10 seeds per meter in 70 cm row widths.

A split-plot randomized block design was used where the main plots consisted of different materials applied as foliar fertilization and the subplots of different times of application. The experiment had 2 replications. The size of the plots was 4 rows by 12 m for the main plot and 4 rows by 4 m for the subplots. The main treatments were check; nitrogen at a rate of 34 kg/ha; nitrogen, phosphorus, potassium at a rate of 7-21.4-36 kg/ha, respectively; nitrogen plus sucrose at a rate of 34 and 150 kg/ha, respective; nitrogen, phosphorus, potassium, sucrose at a rate of 41-21.4-36-150 kg/ha, respectively; and nitrogen, phosphorus, potassium, sulfur, sucrose at a rate of 49-21.4-36-9-150 kg/ha, respectively.

Each main treatment was divided into three subplots in order to spray them at three different times during the seed-filling period. Each of the three "time of application" subtreatments consisted of two spray applications which contained at each time one-half of the total amount of nutrients prescribed for the main treatment.

Solutions were prepared so 750 liters contained the desired amounts of N, P, K and/or S and sucrose for application to one hectare. Urea was used as the primary source of N. Allied Chemical Corp. Formulation RES20426, 3-8.7-15 with 62% of the P as polyphosphate was used as the source of P and K. $(NH_4)_2SO_4$ was used as a source of S.

The concentration of the solution containing urea as a source of N was 5%; in the case of P and K the concentrations were 1.43 and 2.46%, respectively. Each spray solution contained 0.1% Tween 80. Fertilizer solutions were sprayed on the plants using hand portable pressure sprayers with a controlled air pressure of 30 lb/cm^2. The leaves were sprayed from above in such a way as to cause adherence of a maximum amount of solution with little loss by dripping. The spraying was done after sunset between 8 and 10 PM. Sprayings were timed according to the morphological stages of plant development between stages R4 and R7 as described by Fehr et al. (1971).

At stage R4 the plants have a pod 2 cm long at one of the four uppermost nodes with a completely unrolled leaf. At stage R5 beans are beginning to develop (can be felt when the pod is squeezed) at one of the four uppermost nodes. At stage R7 the plants are physiologically mature, 50% of leaves are yellow.

The three "time of application" subtreatments were: treatment 1 at stages R4 and R5 (August 16 and 23), treatment 2 at stages R5 and R6 (August 23 and September 13), and treatment 3 at stages R6 and R6.5 (September 13 and 21). Samples of the youngest mature leaf were taken for each treatment starting at stage R4 and continued before each spray application until stage R6.5. The total number of samples taken between the above stages for each treatment was four.

All dried samples were ground in a Wiley Mill using a 40-mesh screen. All samples were digested in H_2SO_4 and analyzed for total N, P and K as proposed by Dunphy (E. J. Dunphy, 1972, Analyzing plant samples for N, P and K from a single H_2SO_4 digest. Mimeographed paper. Agronomy Department, Iowa State University, Ames, Iowa). Total sulfur was analyzed using the procedure of Tabatabai and Bremner (1971). Plant material was digested with nitric and perchloric acids, and the sulfur content of an aliquot was determined turbidimetrically as $BaSO_4$ by a barium chloride-gelatine procedure. Additional analyses of the plant samples for Ca, Mg, Na, Mn, Fe, B, Cu, Zn, Al and Mo were made by arc-emission spectrographic analysis at the Ohio Plant Analysis Laboratory.

On September 22, a frost affected the plants in such a way that the upper leaves froze. A second frost occurred on September 29 which frosted all leaves. The experiment was harvested on October 18 by cutting at ground level the interior 3 meters of the second and third row of each split plot, and threshing in a plot thresher. The threshed seed was kept in a cloth bag, and allowed to dry to a constant moisture content before weighing. Soybean samples were taken from each treatment and ground in a Wiley Mill using a 40-mesh screen. N, P, K and S analyses were run following the same procedures described above. Ca, Mg, Na, Mn, Fe, B, Cu, Zn, Al and Mo were analyzed at the Ohio Plant Analysis Laboratory.

B. Results and Discussion

1. Soybean yields

Table 44 of the Appendix shows the soybean yields obtained from individual plots of the experiment in 1974. All yields were adjusted to 13.5% moisture. There was a significant effect for treatments for different times of application and as well for the interaction between them. The maximum yield attained in the experiment was 2.799 ton/ha[1] which was obtained from replication 1 for the treatment of 49-21.4-36-9-150 applied during stages R5-6 and R6-6.5. The lowest yield (2.223 ton/ha) was obtained from the check plot in replication 1. Table 1 shows the effect on average yields of the different nutrient solution treatments at different stages of plant development.

Differences in yields and seed sizes were analyzed statistically by Duncan's Multiple Range Test using actual yields and seed sizes. However, in Table 1 the effects of foliar treatments are shown as yield increases to make differences among yields more readily apparent. Actual yields can be calculated by adding the yield increases to the yields of the untreated check plots.

In spite of unfavorable weather conditions through the season (unusually hot and dry weather in July restricted plant growth and development during midsummer; early frosts stopped bean development before normal maturity), foliar applications of fertilizer nutrients increased soybean yields. The largest yield increases, 470 kg/ha and 540 kg/ha, were obtained from spray applications that contained all four nutrient elements--N, P, K, and S. Spray applications that contained only N or N, P and K resulted in smaller increases in yield.

Although including sucrose in the spray solution of N at

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[1]In all future references 1 ton = 1000 kg.

Table 1. Effects on soybean yields of foliar application of different solutions at different stages of plant development[a]

Foliar treatment	Trt. no.	Soybean yield (kg/ha): Time of foliar application R4-5	R5-6	R6-6.5	Average
Check	1	2290 c	2270 e	2230 b	2263 c
N-P-K-S (kg/ha)		Yield increase from foliar treatment			
34-0-0-0	2	130 b	220 d	160 b	170 bc
34-0-0-0-150[b]	3	360 a	310 bc	180 b	283 ab
7-21.4-36-0	4	130 b	250 cd	140 b	173 bc
41-21.4-36-0-150[b]	5	80 bc	360 ab	230 b	223 bc
49-21.4-36-9-150[b]	6	80 bc	470 a	540 a	363 a
Average		160 a	320 b	250 a	

[a]Values for individual treatments within a column and for averages within the last row not followed by the same letter differ significantly at the 5% level.

[b]Spray solution contained sucrose at a rate of 150 kg/ha.

stages R4 and R5 resulted in a significant yield increase, all other comparisons of treatments with and without sucrose indicate that sucrose had little or no effect on soybean yields.

The reason for the possible beneficial effect of sucrose when applied with urea at the earlier stage of development is unknown; however, it seems reasonable that the sucrose forms a syrup as the water evaporates and prevents the urea from attaining a toxic concentration. On the other hand, there may be chemical interaction between urea and sucrose. Ellerton and Dunlop (1966) reported the formation of urea-urea and urea-sucrose dimers in solution. These dimers would reduce the toxicity due to the effect of solutes in increasing the solute suction of the solution while it was on the leaves. Nevertheless, the magnitude of these effects does not seem to be great enough to account for either the low toxicity of urea alone or the reduction in toxicity of urea when it is mixed with sucrose. Two other possible explanations are that both sucrose and urea produce approximately neutral solutions and neither sucrose nor urea is ionic.

The most consistent yield increases from foliar applications of fertilizer nutrients resulted from the treatments that consisted of applications at both R5 and R6. Applications at earlier stages, R4 and R5, generally resulted in smaller yield increases. All applications at the later stages, R6 and R6.5, resulted in no significant yield increase with the exception of treatment no. 6 which produced essentially the same yield increase as the one that was obtained when this treatment was applied during stages R5 and R6. This shows that application of a complete solution of N, P, K, S is necessary to obtain significant increases in yield and that when the rate of application is 49-21.4-36-9 the effect is similar when applied at stages R5-6 or R6-6.5.

2. Chemical analysis of leaves and grain

Tables 2, 3, and 4 show values of N, P, K, S in leaves and grain for each treatment at different stages of development (R4-5, R5.5-6, and R6-6.5) and at each sampling time.

The nutrient content in the leaves decreased steadily with time for each of the three subtreatments. Comparing the nutrient content between treatments at the same time of sampling but at different "times of application" shows that there was not very much variation between them and that the concentrations of N, P, and K tended to be similar no matter what subtreatments are compared. The only exception to this was with subtreatment no. 2 (sprayed during stage R5.5-6) in which the N and P contents at sampling time R6.7 was considerably higher than the other 2 subtreatments (Table 5). This could explain the higher yields obtained for all the treatments when the foliar spray was applied during stages R5.5-6 due to the fact that in spite of the active translocation of nutrients from the leaves to the seeds during this stage of development (Hanway and Weber, 1971d) the concentration of nutrients in the leaves did not decrease to low levels (N-2.75%, P-0.28%, and K-0.75% in the check) during this period, due to the foliar fertilization. As a consequence of this, there was not a complete depletion of nutrients of the leaves which in turn would avoid a decreasing rate of photosynthesis.

Analyses of variance were calculated at each sampling time within each "time of application" to detect differences in

Table 2. N, P, K, S contents in leaves and beans after spraying during stages R4-5, 1974

Trt. no.	Time of sampling[a]								
	Leaves R5			Leaves R5.5			Leaves R6		
	% N	% P	% K	% N	% P	% K	% N	% P	% K
1	5.26	0.60	2.10	4.65	0.50	1.96	3.40 d	0.39	1.08 c
2	5.32	0.66	2.10	4.61	0.51	1.91	4.12 a	0.38	1.31 ab
3	5.22	0.59	2.26	4.71	0.51	1.96	3.85 bc	0.34	1.42 a
4	5.28	0.66	2.22	4.42	0.50	1.95	3.90 abc	0.41	1.20 b
5	5.02	0.64	2.23	4.59	0.51	2.05	3.77 c	0.41	1.31 ab
6	5.18	0.67	2.13	4.70	0.50	1.96	4.04 ab	0.38	1.26 ab

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

Time of sampling							
Leaves R6.7			Beans - harvest				
% N	% P	% K	% N	% P	% K	% K	% protein
2.75 bc	0.28	0.75	6.08	1.00	2.08	0.29	38.00
3.07 ab	0.29	0.95	6.29	1.02	2.08	0.28	39.31
3.07 ab	0.32	0.94	5.97	1.04	2.12	0.31	37.31
2.48 c	0.35	1.01	5.98	1.06	2.08	0.30	37.38
3.16 a	0.38	1.02	6.02	1.01	2.13	0.29	37.63
3.04 ab	0.33	1.11	6.36	1.05	2.09	0.33	39.75

Table 3. N, P, K, S contents in leaves and beans after spraying during stage R5.5-6[a]

Trt. no.	Time of sampling					
	Leaves R5.5			Leaves R6		
	% N	% P	% K	% N	% P	% K
1	4.65	0.50	1.96	3.40 d	0.39	1.08
2	4.50	0.48	1.97	4.18 a	0.41	1.53
3	4.72	0.44	1.91	3.87 bc	0.41	1.16
4	4.32	0.47	1.87	4.02 ab	0.41	1.21
5	4.54	0.47	1.87	3.72 c	0.37	1.08
6	4.52	0.45	1.91	4.13 a	0.41	1.09

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

Time of sampling							
Leaves R6.7			Beans - harvest				
% N	% P	% K	% N	% P	% K	% S	Protein
2.75 c	0.28 b	0.75	6.08	1.00	2.08	0.29	38.00
3.54 a	0.36 ab	0.84	6.38	1.00	2.02	0.29	39.88
3.49 a	0.35 ab	1.02	6.14	1.07	2.08	0.32	38.38
2.94 bc	0.47 ab	1.12	6.46	1.10	1.98	0.29	40.38
3.06 ab	0.43 a	1.02	6.28	1.05	2.13	0.29	39.25
3.28 ab	0.38 ab	0.88	6.29	1.03	2.05	0.33	39.31

Table 4. N, P, K. S. contents in leaves and beans after spraying during stage R6-6.5[a]

	Time of sampling							
	Leaves R6.7			Beans - harvest				
Trt. no.	% N	% P	%K	% N	% P	% K	% S	Protein
1	2.62 b	0.29 c	0.77	6.08	1.00	2.04	0.29 b	38.00
2	3.59 a	0.36 ab	0.78	6.52	1.02	1.96	0.28 b	40.75
3	2.99 ab	0.34 bc	0.77	6.65	1.06	2.04	0.28 b	41.56
4	2.72 b	0.40 a	0.75	6.16	1.04	2.00	0.25 c	38.50
5	2.97 ab	0.42 a	0.95	6.27	0.98	2.00	0.31 ab	39.19
6	3.15 ab	0.37 ab	0.83	6.33	1.07	2.04	0.33 a	39.56

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

Table 5. N, P, K contents in leaves at stage R6.7 and after spraying during stages R4-5, R5.5-6, R6-6.5, 1974 experiment

Time of application	Leaves[a] N %	Leaves[b] P %	Leaves[b] K %
R4-5 (1)	2.96	.35	1.05
R5.5-6 (2)	3.26	.43	1.01
R6-6.5 (3)	3.08	.40	.84
Check	2.75	.28	.75

[a]Average of all the treatments less no. 1.

[b]Average of all the treatments less no. 1, 2, 3.

nutrient content (N, P, K) due to the effect of treatments (Tables 2, 3, 4). There was a significant effect due to treatments in the concentration of N during stage R6 and R6.7 when the foliar fertilizer was sprayed either in stages R4-5 R5.5-6, or R6-6.5 (subtreatments no. 1, 2, and 3, respectively).

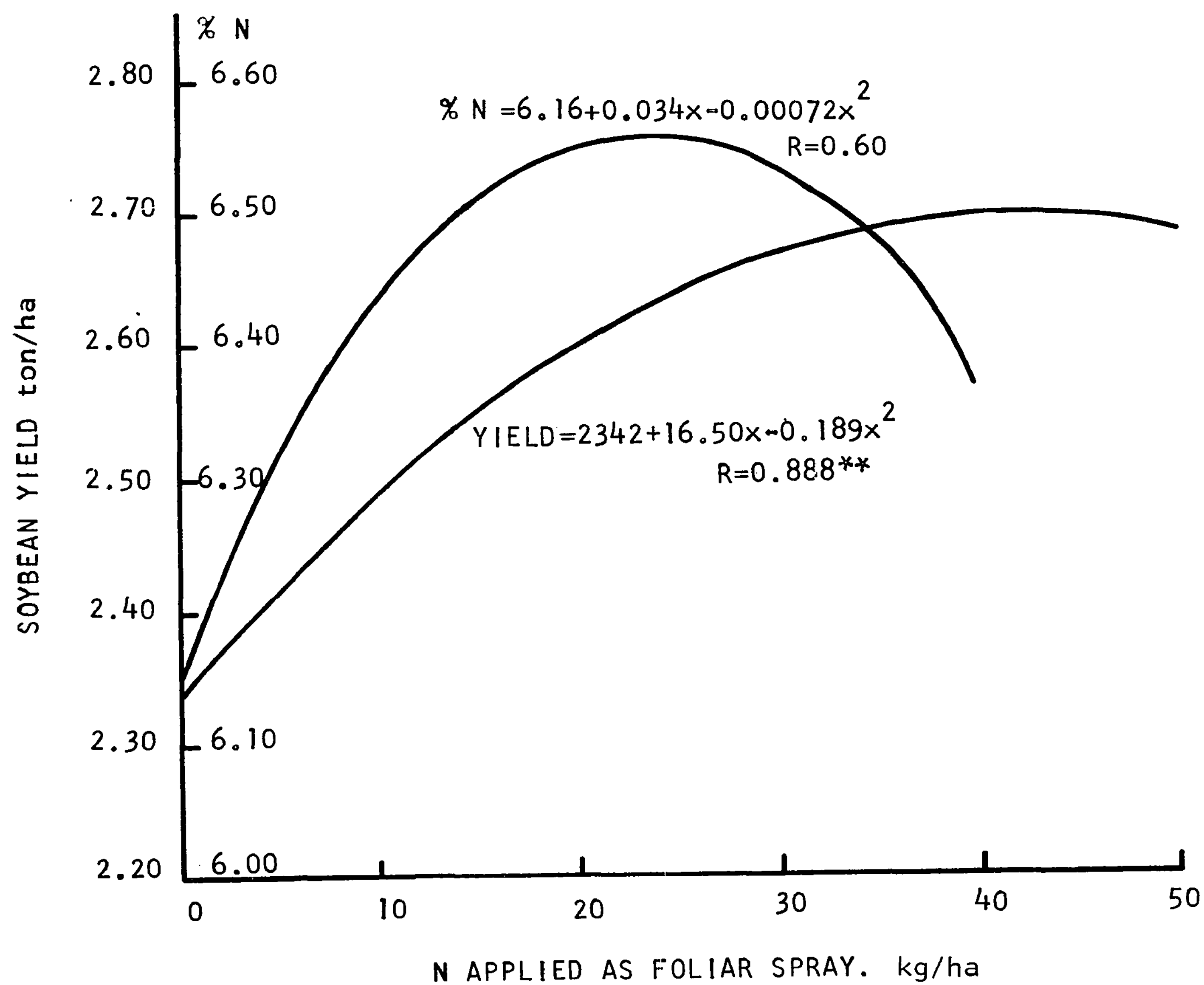
In the case of P this effect was significant only during stage R6.7 and when the plants were sprayed during stages R5.5-6 and R6-6.5 (subtreatments no. 2 and 3, respectively). The 6 treatments significantly differ in their contents of K only during stage R6 and when the fertilizers were sprayed during stages R4-5 (subtreatment no. 1, Table 2). Comparing the yield data in Table 1 with the nutrient content at the different stages of development and considering only the sampling dates where a significant effect due to treatments was detected, it can be observed that the treatment which resulted in the highest yield at either "time of application" 2 or 3 also has the highest statistically significant values for N, P, or K at stages of development R6 and R6.7. Again this corroborates what was postulated before that in order to counteract the active translocation of nutrients from the leaves to the grain, application of nutrients to the leaves during this period kept the nutrient content of the leaves at higher levels, which in turn resulted in higher yields.

In order to have an idea of the type of response to the addition of increased doses of nitrogen at stage R5.5-6, 4 treatments were selected (check; 7-21.4-36.0; 41-21.4-36-0; 49-21.4-36-7) and a quadratic model was adjusted through the regression procedure.

Figure 1 shows the adjusted curves and the regression equation obtained for the variable yield and percent of N in the beans.

It can be observed from the response curve that the maximum yield was obtained when between 40 and 50 kg of N was applied (calculated maximum yield of 2702 kg of soybeans per ha was obtained with 43.65 kg of N/ha). On the other hand, the maximum content of N in the beans was obtained when between 20 and 30 kg of N were applied (calculated maximum N content of 6.56% was obtained with 23.61 kg N/ha). As the amount of N applied increased there was more production of grain beyond the point of maximum % N in the grain. At this

Figure 1. Effect of nitrogen foliar fertilization during stage R5.5-6 on soybean yields and % N in the beans, 1974 experiment


SOYBEAN YIELD ton/ha
% N
2.80
2.70
2.60
2.50
2.40
2.30
2.20
6.60
6.50
6.40
6.30
6.10
6.00
% N =6.16+0.034x-0.00072x2
R=0.60
YIELD=2342+16.50x-0.189x2
R=0.888**
0
10
20
30
40
50
N APPLIED AS FOLIAR SPRAY. kg/ha

point probably all the N in the plant is diverted to form protein in the extra grain and dry matter being produced so even after translocation from the leaves and after considering the amount that was applied as foliar fertilization, the total quantity of N was just enough to account for the extra grain produced but not to increase the N content of the grain.

Figures 2, 3 and 4 show the variation in the N, P and K contents of the leaves with time following different foliar spray treatments applied during stage R5.5-6. As pointed out before, the nutrient contents late in the growing season were higher for the treatments in which the nutrient was applied at a higher rate. All the treatments resulted in higher values for N, P and K than were found in the check plots after stage of development R6.

Figures 5, 6 and 7 show the variations in the N, P and K contents of the leaves with time following treatment no. 6 (49-21.4-36-9) at 2 times of application, R4-5 and R5.5-6. The reason for using treatment no. 6 as a source of comparison is because with this treatment, when it was applied during stages R5-5.5, the highest yields were obtained. It can be observed in these graphs that the concentrations of N and P in the leaves were higher when the nutrients were sprayed during stages R5.5-6 (subtreatment no. 2), than when sprayed at stages R4-5 (subtreatment no. 1) or the check.

Simple linear correlations were computed between the analytical values of the leaves (at different times of sampling)

Figure 2. Variation of N content in the leaves with time under different foliar spray treatments applied during stages R5-5.5, 1974 experiment

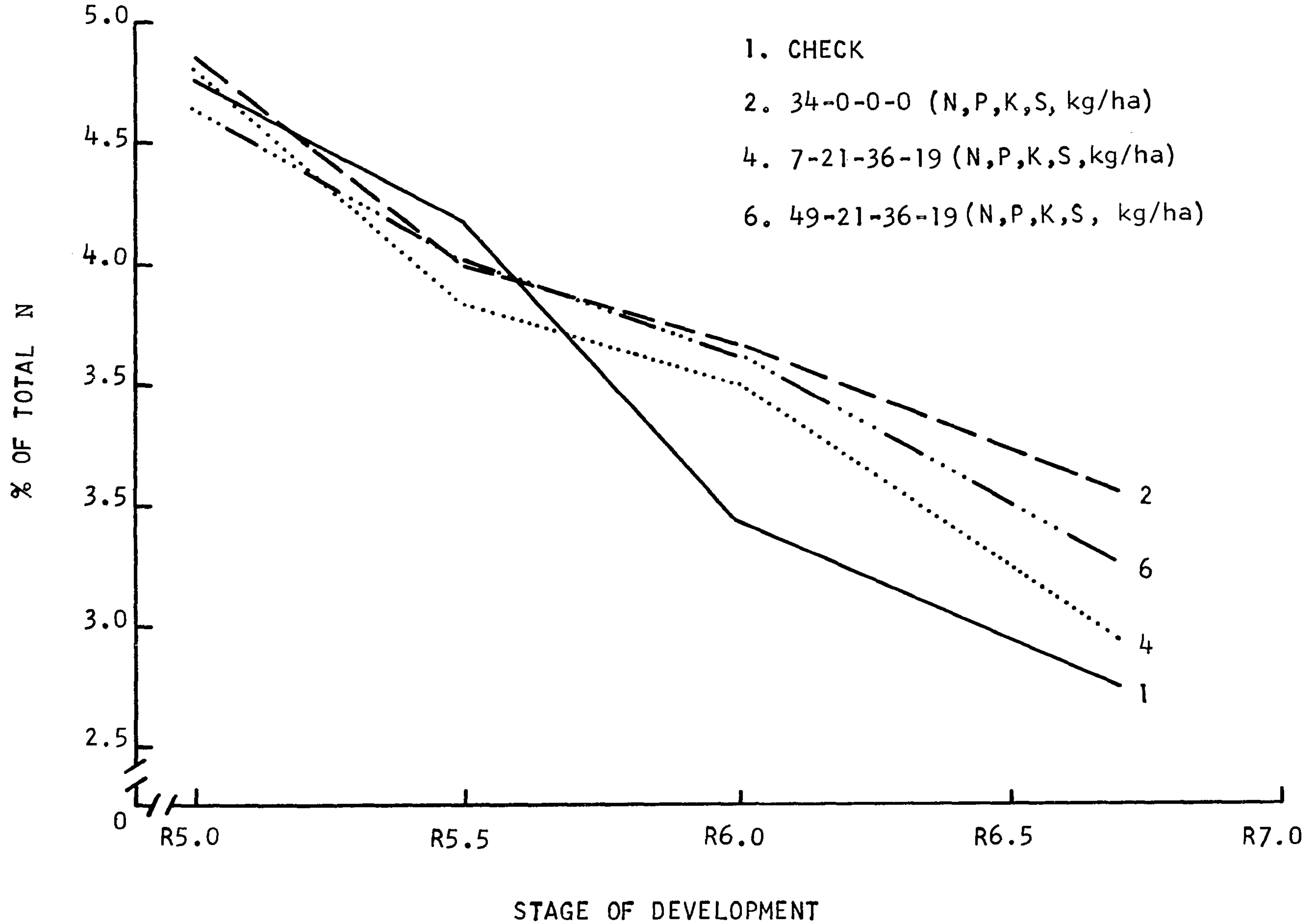

1. CHECK
2. 34-0-0-0 (N,P,K,S, kg/ha)
4. 7-21-36-19 (N,P,K,S,kg/ha)
6. 49-21-36-19 (N,P,K,S, kg/ha)
% OF TOTAL N
5.0
4.5
4.0
3.5
3.5
3.0
2.5
0
R5.0
R5.5
R6.0
R6.5
R7.0
2
6
4
1
STAGE OF DEVELOPMENT

Figure 3. Variation of P content in the leaves with time under different foliar spray treatments applied during stages R5-5.5, 1974 experiment

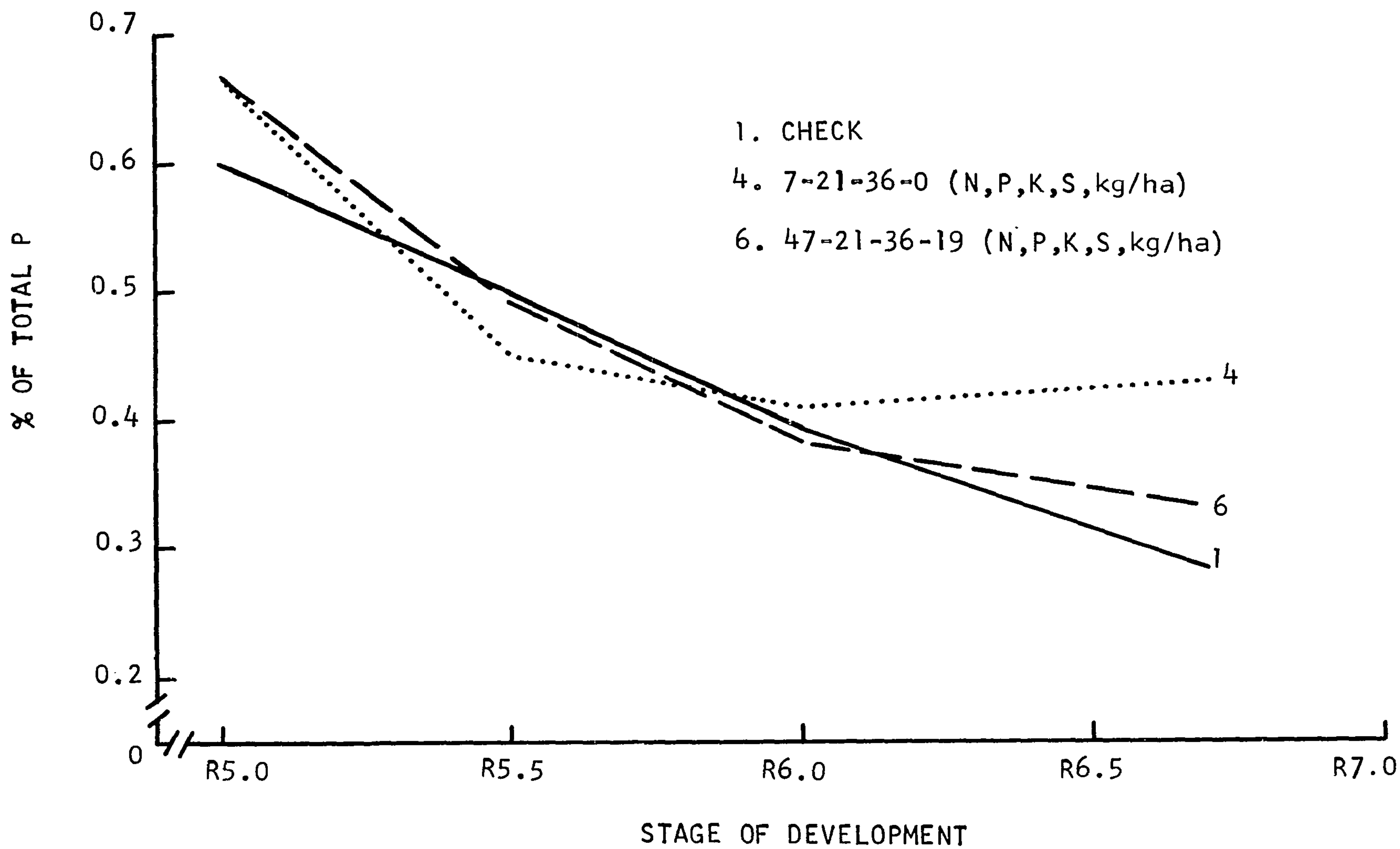

0.7
0.6
0.5
0.4
0.3
0.2
0
% OF TOTAL P
1. CHECK
4. 7-21-36-0 (N,P,K,S,kg/ha)
6. 47-21-36-19 (N,P,K,S,kg/ha)
4
6
1
R5.0
R5.5
R6.0
R6.5
R7.0
STAGE OF DEVELOPMENT

Figure 4. Variation of K content in the leaves with time under different foliar spray treatments applied during stages R5-5.5, 1974 experiment

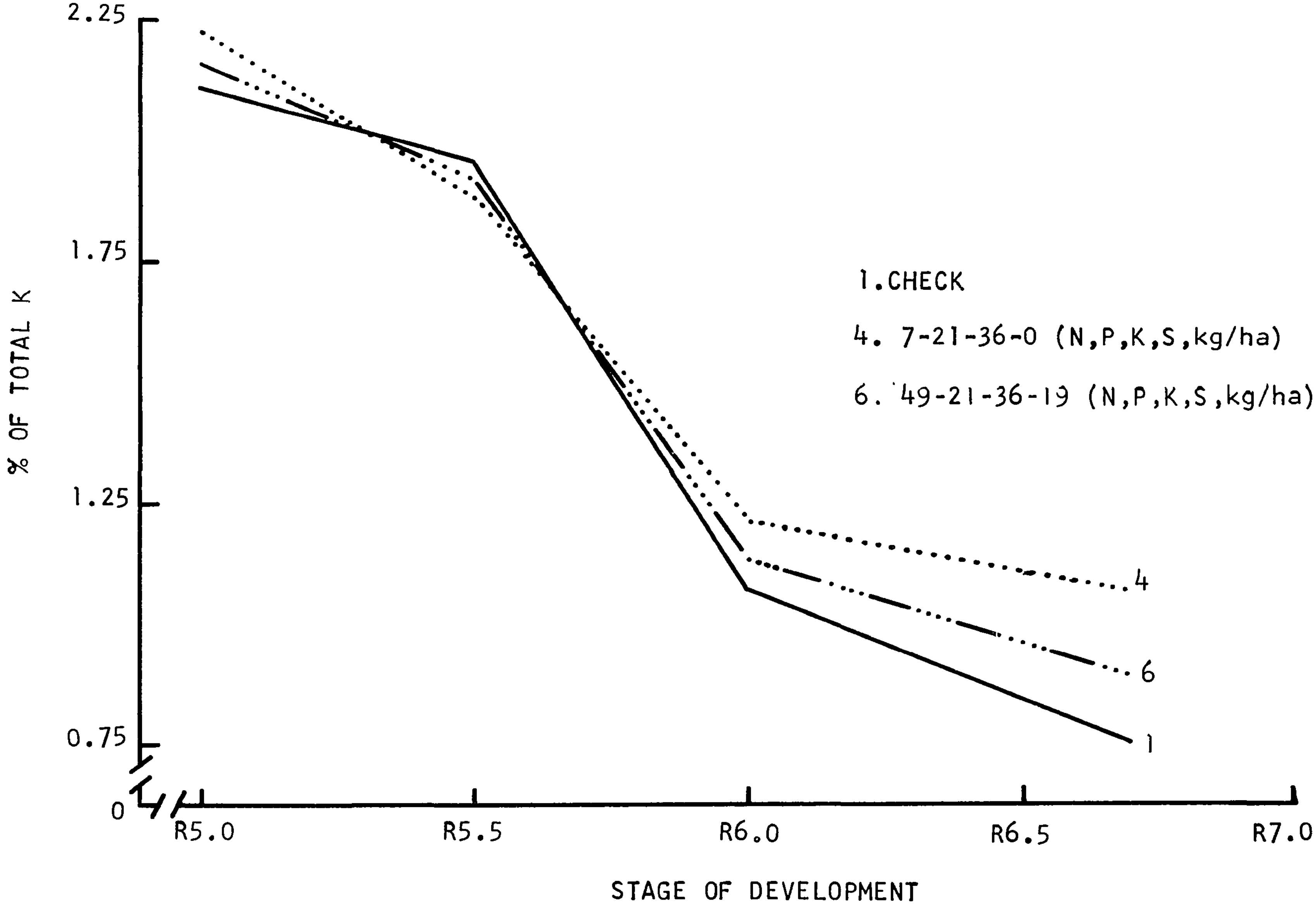

2.25
1.75
1.25
0.75
0
% OF TOTAL K
1.CHECK
4. 7-21-36-0 (N,P,K,S,kg/ha)
6. 49-21-36-19 (N,P,K,S,kg/ha)
4
6
1
R5.0
R5.5
R6.0
R6.5
R7.0
STAGE OF DEVELOPMENT

Figure 5. Variation of N content in the leaves with time for treatment 6 (49-21-36-9), after spraying, during stages R4-5 and R5.5-6, check plot is used for comparison, 1974 experiment

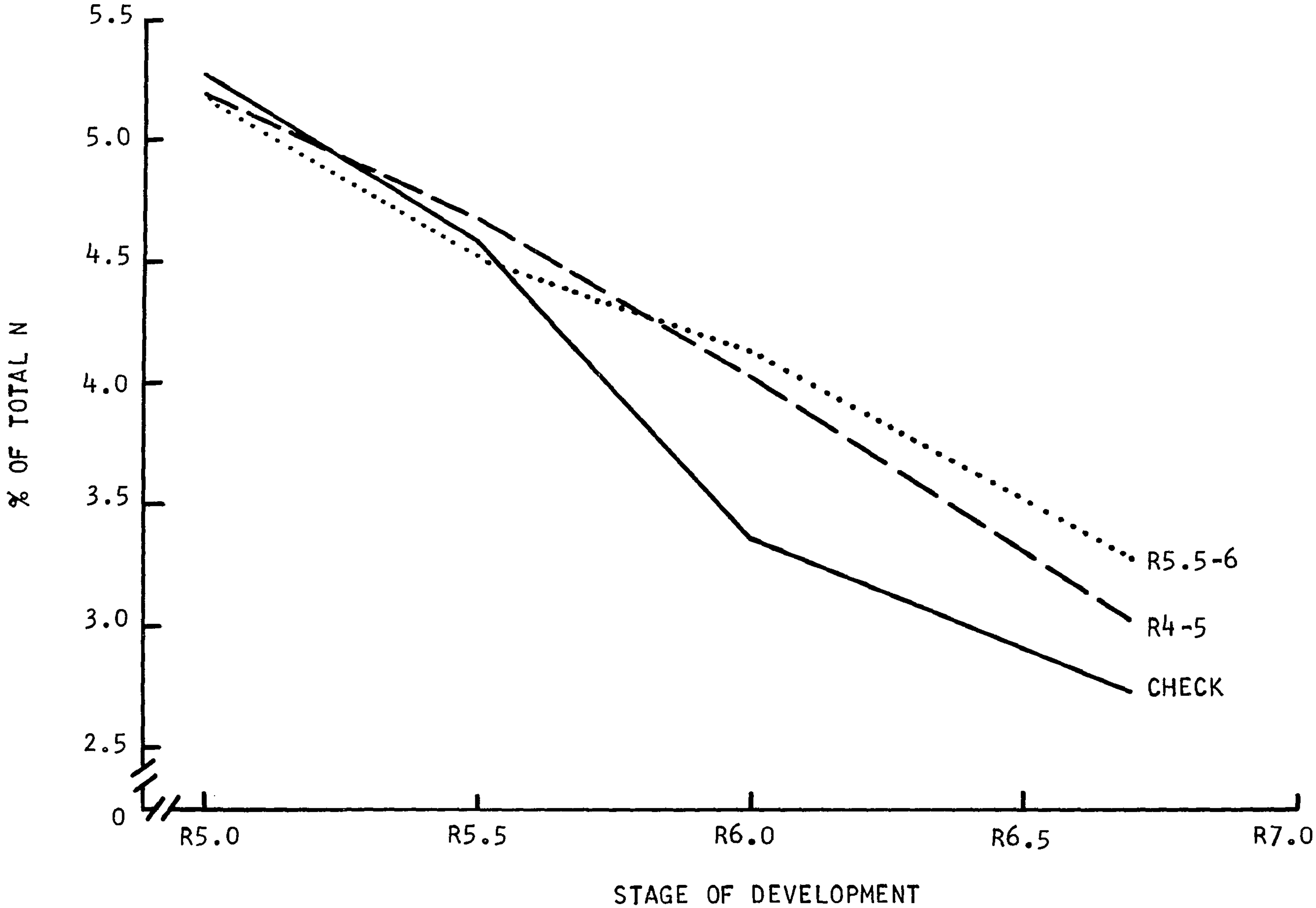

5.5
5.0
4.5
4.0
3.5
3.0
2.5
0
% OF TOTAL N
R5.0
R5.5
R6.0
R6.5
R7.0
STAGE OF DEVELOPMENT
R5.5-6
R4-5
CHECK

Figure 6. Variation of P content in the leaves with time for treatment 6 (49-21-36-9), after spraying, during stages R4-5 and R5.5-6, check plot is used for comparison, 1974 experiment

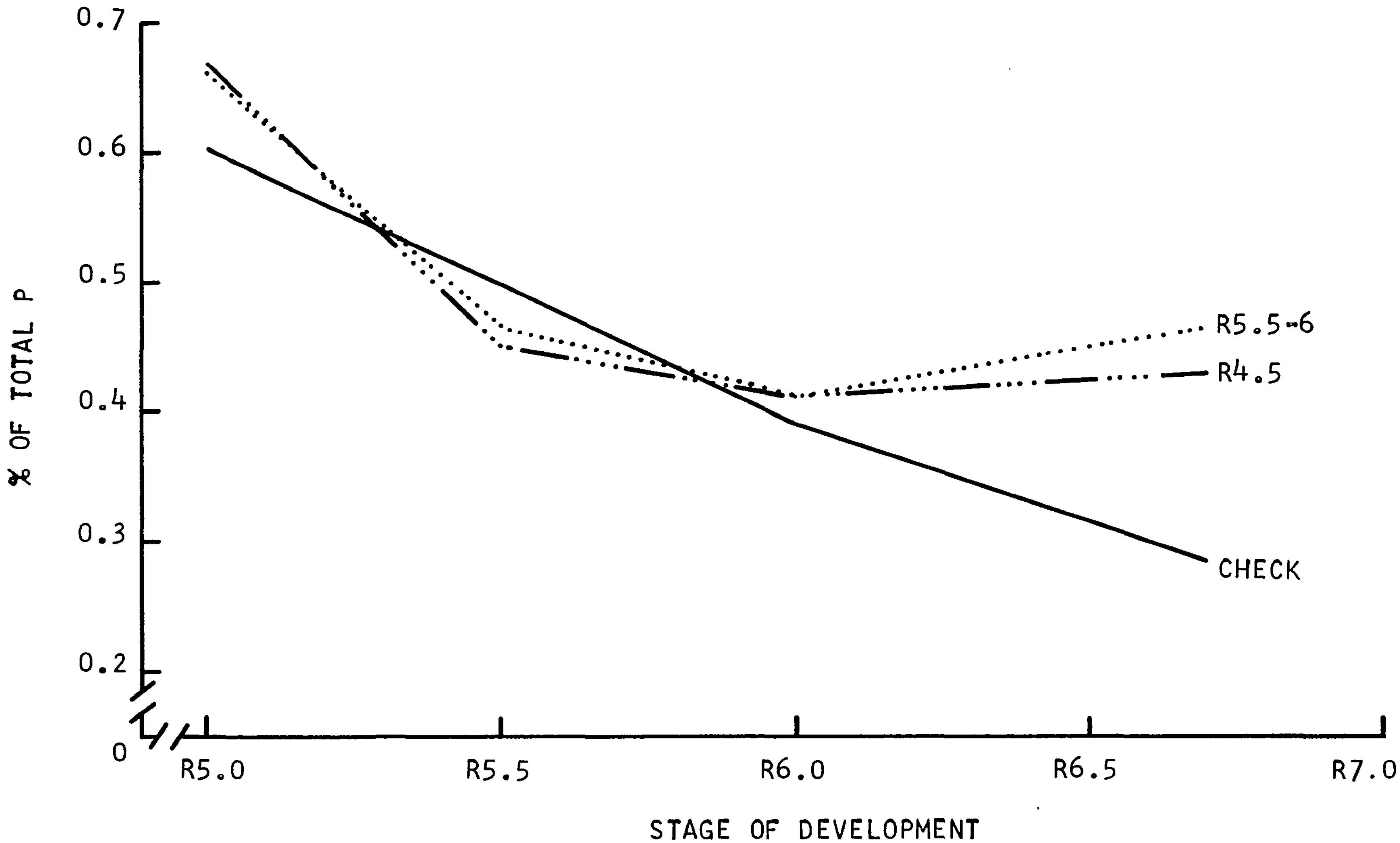
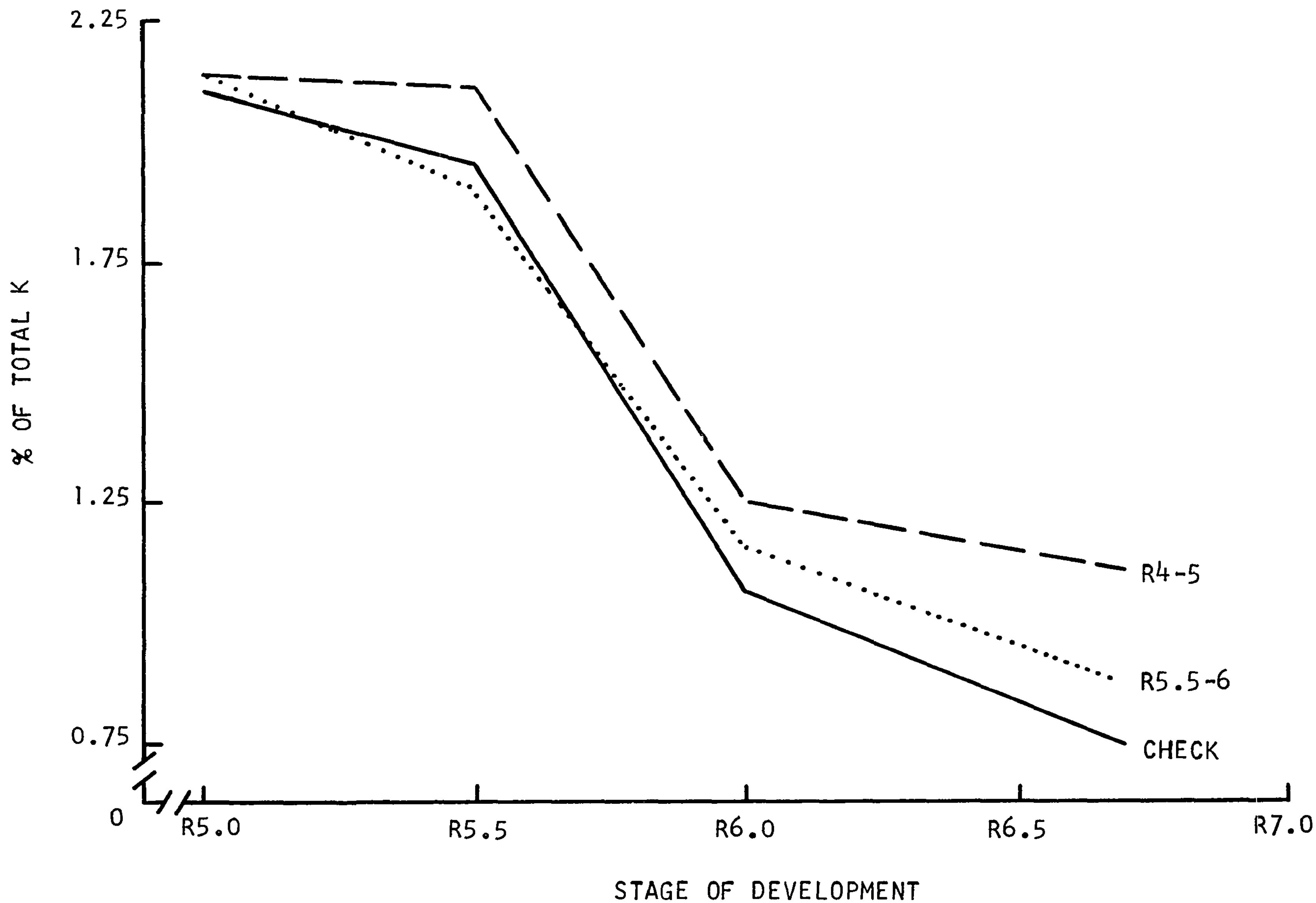

0.7
0.6
0.5
0.4
0.3
0.2
0
% OF TOTAL P
R5.5-6
R4.5
CHECK
R5.0
R5.5
R6.0
R6.5
R7.0
STAGE OF DEVELOPMENT

Figure 7. Variation of K content in the leaves with time for treatment 6 (49-21-36-9), after spraying, during stages R4-5 and R5.5-6, check plot is used for comparison, 1974 experiment


2.25
1.75
1.25
0.75
0
% OF TOTAL K
R4-5
R5.5-6
CHECK
R5.0
R5.5
R6.0
R6.5
R7.0
STAGE OF DEVELOPMENT

with the analytical values of the leaves at other times of sampling and the beans at harvest and with the yield obtained in each treatment, in order to have a better understanding of the degree of association between these variables. Three correlation matrices were obtained, each one corresponding to each "time of application" subtreatment. The correlation coefficients involving the variables which had a probability of occurrence under the null hypothesis of 10% or less are summarized in Tables 6, 7 and 8.

There was a positive significant correlation between yield and K content in the leaves at stage R6 after the plants had been sprayed during stage of development R4-5 (r = 0.711**). This is illustrated in Figure 8, and indicates that when the K is applied at stage R4-5, even during stage R6, the content of the nutrient in the leaves has an important role to play in increasing yields. Later, during stage R6.7, the K content of the leaves was still important and a positive significant correlation (r = 0.415**) was found between this and the K content of the beans. The relationship is shown in Figure 9.

After the plants have been sprayed during stage R4-5, the N content of the leaves at stage R5 correlated with the N content at stage R5.5 (r = 0.559*) and later in turn was correlated with the N content of the leaves at stage R6.7 (r = 0.467**). Also the P content of the leaves at stage R6 was significantly correlated with the P content of the leaves at stage R6.7. These correlations show that in the

Table 6. Correlation coefficients between variables within subtreatment "time of application" R4-5

	Leaves									
	Stage 5.5		Stage R6	Stage R6.7			Beans - harvest			
	% N	% P	% K	% N	% P	% K	% N	% P	% K	% S
Yield			0.711**							
Leaves										
R5 % N	0.559*								-0.786**	
R5 % P						0.456***	0.615*			
R5.5 % N		0.448***		0.467***				-0.471***	-0.469***	
R6 % N						0.553*				
R6 % P			-0.451***		0.460***					
R6 % K				0.594*						
R6.7 % K								0.696**	0.415***	0.498***
Beans										
% N										0.455***
% P									0.657**	0.525*

***Significant at 10% level.

*Significant at 5% level.

**Significant at 1% level.

Table 7. Correlation coefficients between variables within subtreatment "time of application" R5.5-6

	Leaves				
	Stage R5.5		Stage R6		
	% P	% K	% N	% P	% K
Yield	-0.559		0.507*		
Leaves					
R5.5 % N					-0.459***
R5.5 % P		0.478***	-0.475***		
R5.5 % K					
R6 % N				0.574*	0.475***
R6 % P					0.544*
R6.7 % P					
R6.7 % K					
Beans % N					

***Significant at 10% level.

*Significant at 5% level.

**Significant at 1% level.

Leaves						
Stage R6.7			Beans - harvest			
% N	% P	% K	% N	% P	% K	% S
	0.465***			0.441*		0.522**
0.547*						0.469***
-0.486***	0.464***					-0.667**
	-0.548*					
0.448***			0.504*		-0.422***	
		0.728**	0.596**	0.486***		
				0.694**		
					-0.527*	

Table 8. Correlation coefficients between variables within subtreatment "time of application" R6-6.5

	Leaves	Beans - harvest	
	R6.7 % K	% K	% S
Yield			0.696**
Leaves R6.7 % K	0.555*		
Beans % P		0.573*	

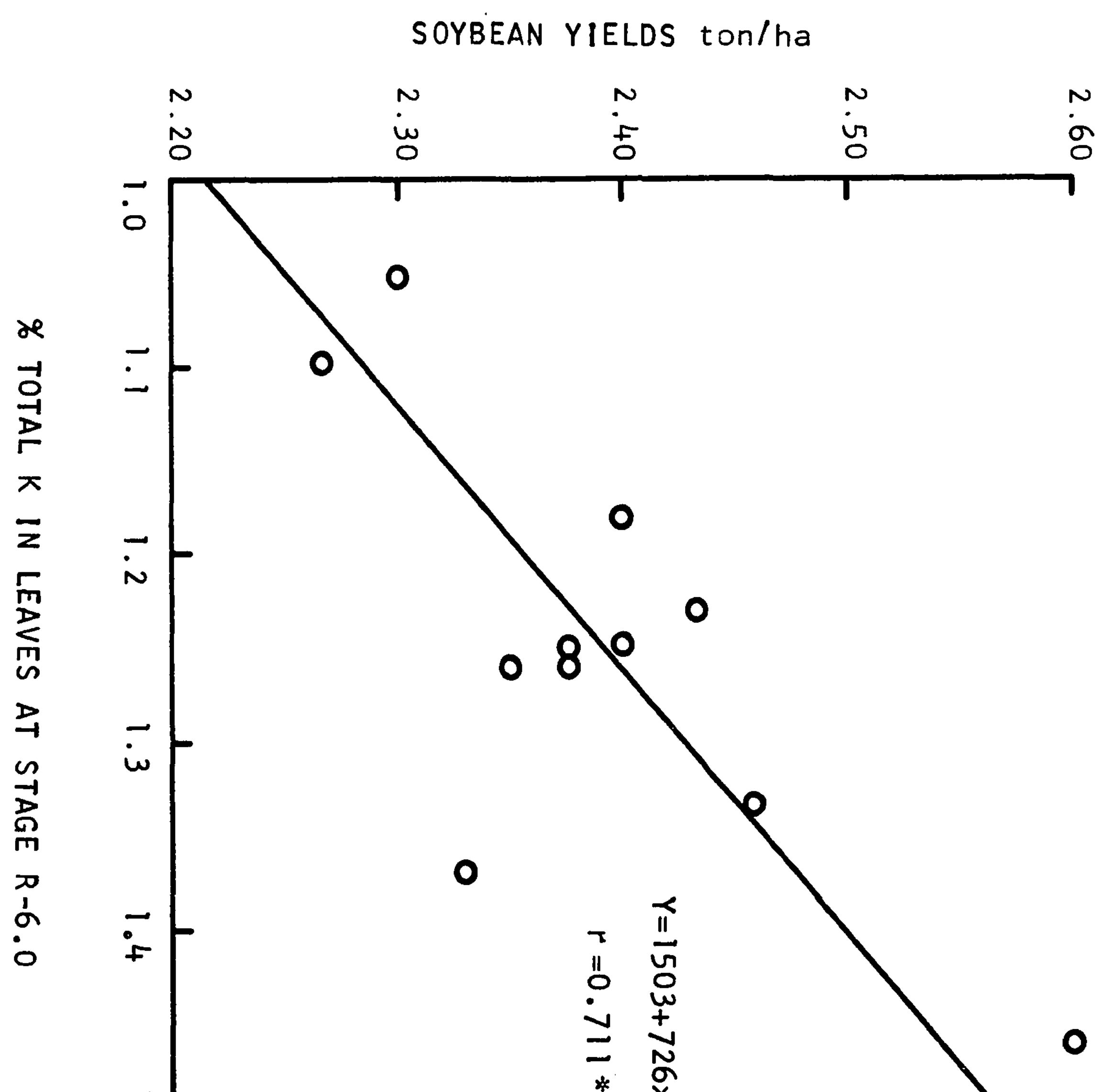
*Significant at 5% level.

**Significant at 1% level.

case of N and P, and when these nutrients were applied earlier at stage R4-5, the initial increase of nutrient content in the leaves due to the spray was maintained through the rest of the stages of development until stage R6.7.

There were positive significant correlations between yield and N and P contents in the leaves at stages R6 and R6.7, respectively (r = 0.507* and 0.465***, Figure 10), after the plants had been sprayed during stage of development R5.5-6. This shows that higher concentrations of these nutrients must be present in the leaves late in the season in order to attain higher yields, and that the nutrient content of the leaves during these stages of development was a good indicator of the nutritional status of the plants. Yield was also correlated with the amount of P and S present in the beans (r = 0.441*** and 0.522*, respectively) after the plants had been sprayed

Figure 8. Relationship between the K content in leaves during stage R6 with yield of soybeans after the plants were sprayed with fertilizer solutions during stage R4-5, 1974 experiment



SOYBEAN YIELDS ton/ha
2.20
2.30
2.40
2.50
2.60
1.0
1.1
1.2
1.3
1.4
1.5
Y=1503+726x
r =0.711 **
% TOTAL K IN LEAVES AT STAGE R-6.0

Figure 9. Relationship between the K content in leaves sampled at stage R6.7 with K content in beans, after the plants were sprayed with fertilizer solutions during stage R4-5, 1974 experiment

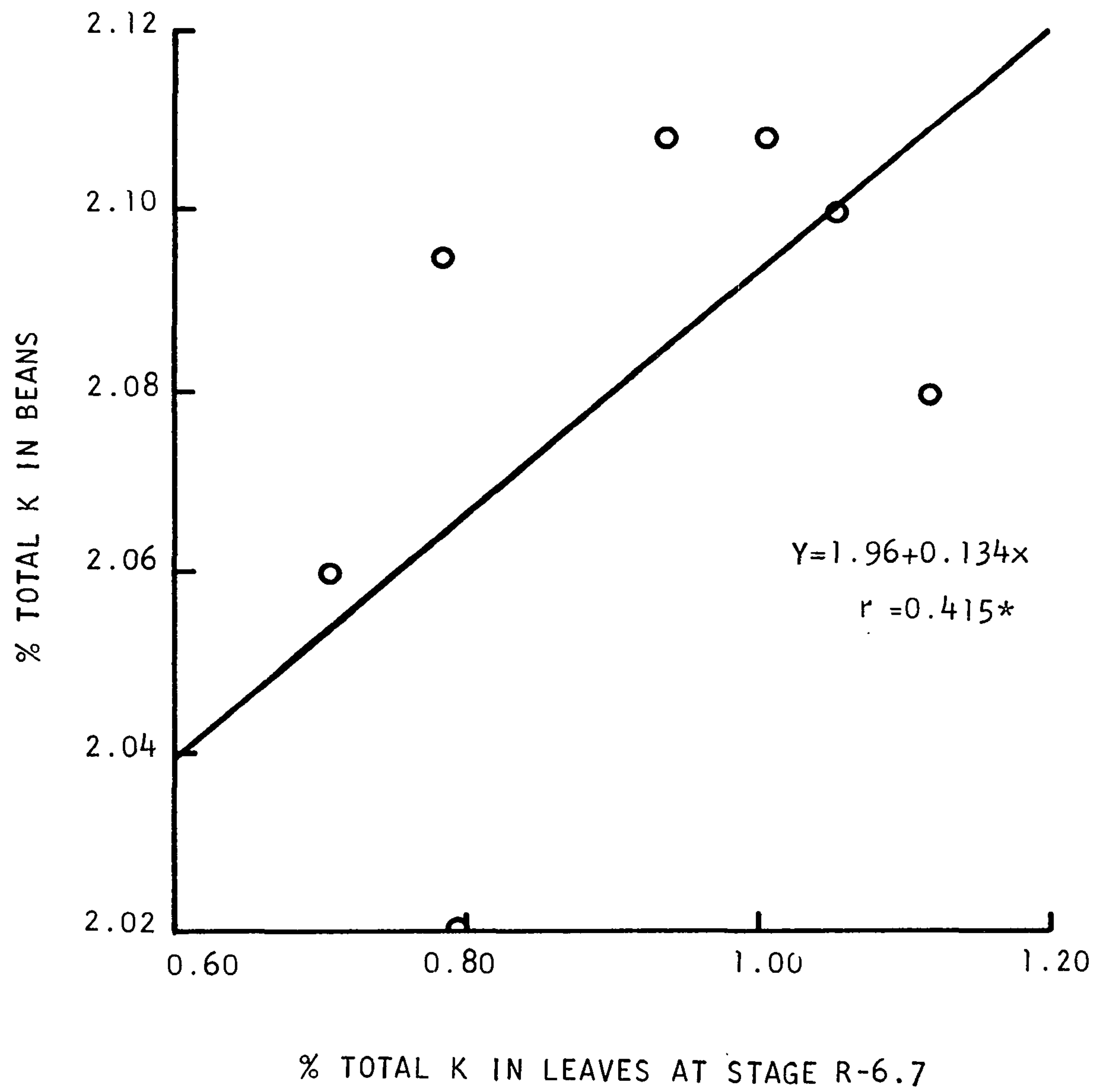
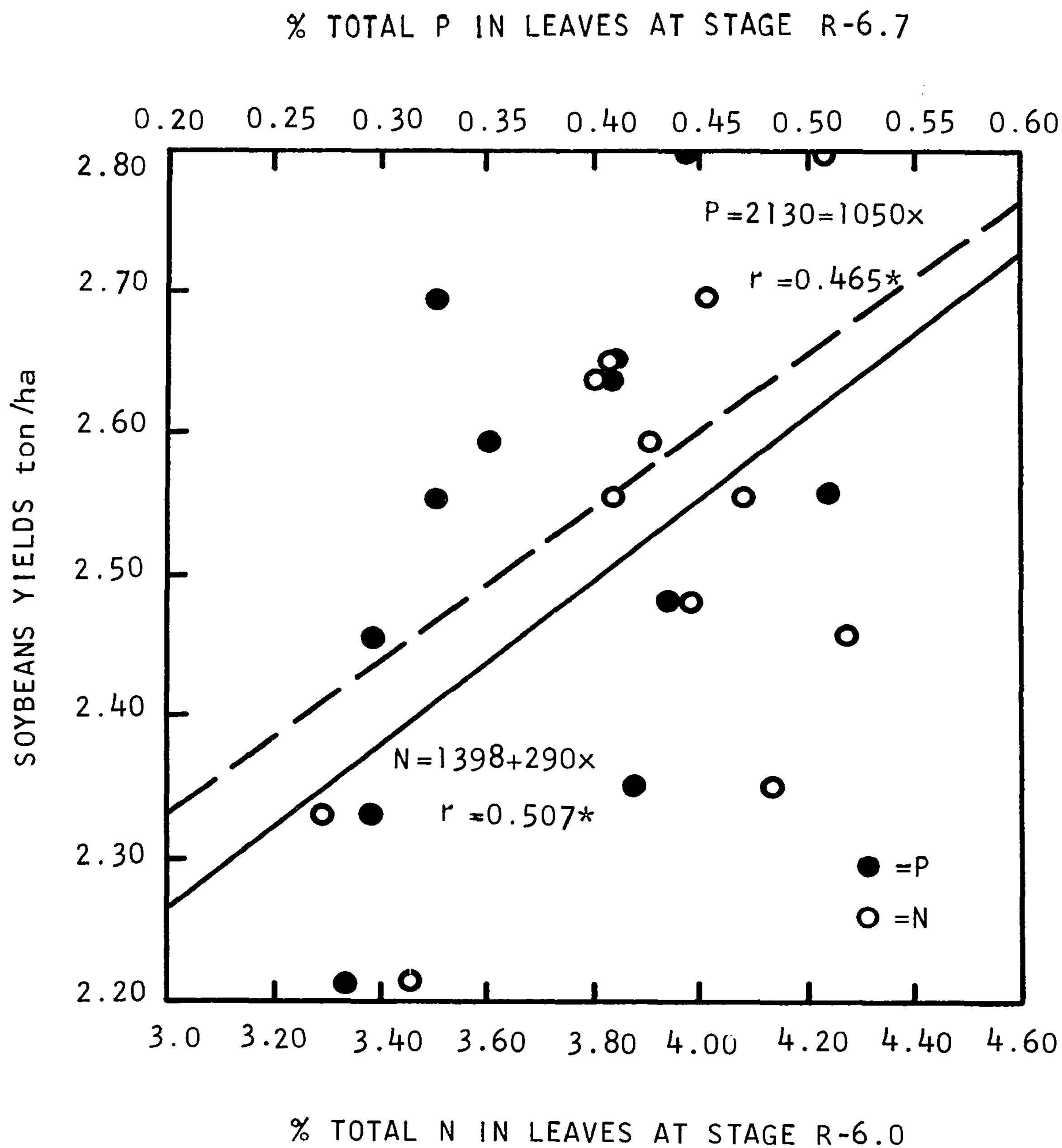

% TOTAL K IN BEANS
2.12
2.10
2.08
2.06
2.04
2.02
0.60
0.80
1.00
1.20
Y=1.96+0.134x
r =0.415*
% TOTAL K IN LEAVES AT STAGE R-6.7

Figure 10. Relationship between the N and P contents in leaves during stages R6 and R6.7, respectively, with soybean yields after the plants were sprayed with fertilizer solutions during stage R5.5-6, 1974 experiment


% TOTAL P IN LEAVES AT STAGE R-6.7
0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60
2.80
2.70
2.60
2.50
2.40
2.30
2.20
SOYBEANS YIELDS ton/ha
P=2130=1050x
r =0.465*
N=1398+290x
r =0.507*
=P
=N
3.0 3.20 3.40 3.60 3.80 4.00 4.20 4.40 4.60
% TOTAL N IN LEAVES AT STAGE R-6.0

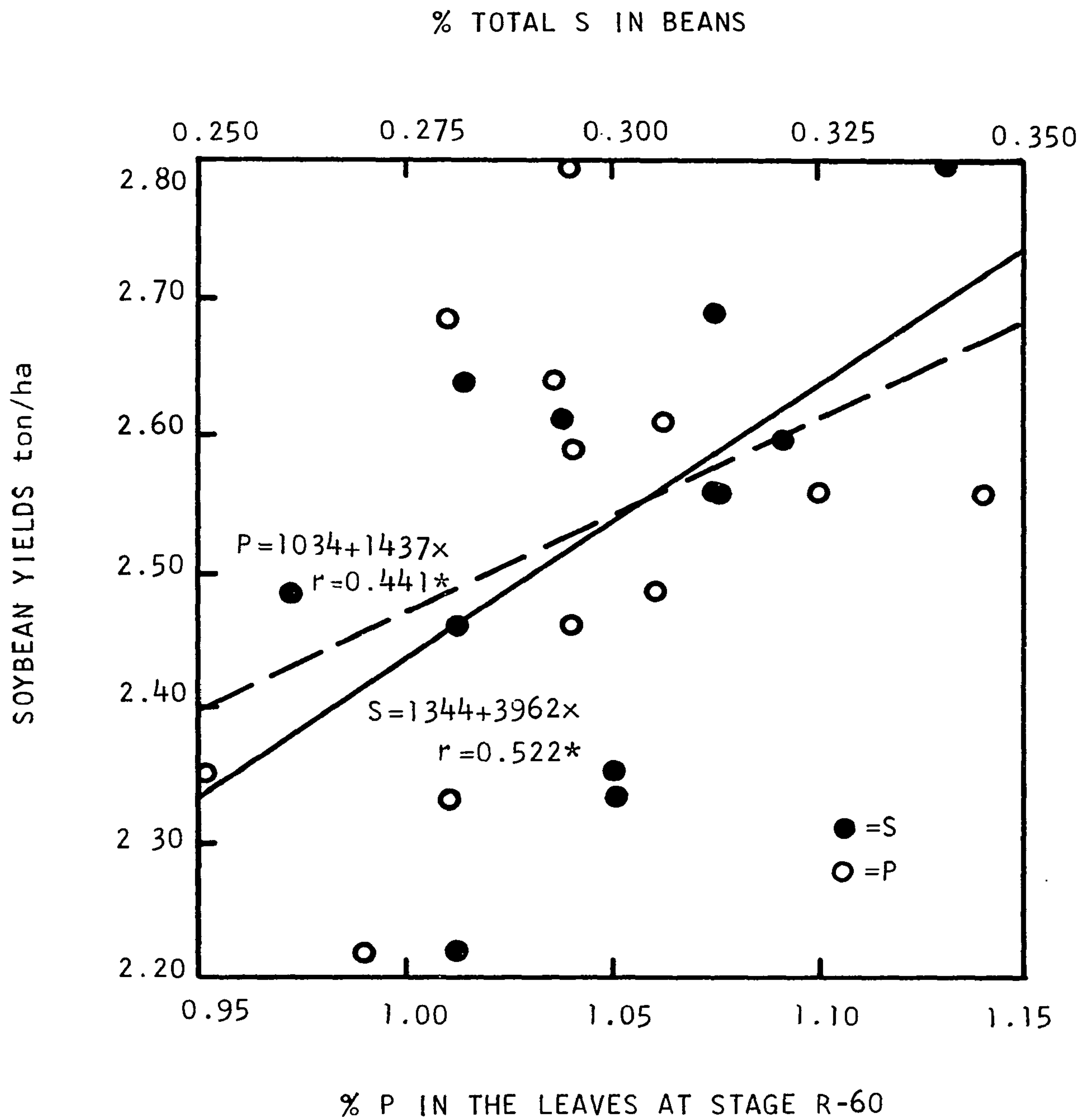
during stage of development R5.5-6 (Figure 11).

As pointed out before for "time of application" R4-5 and considering now time of application R5.5-6 (Table 7) there were significant correlations between N content in the leaves at stage R5.5 and N content at stage R6.7 and in turn between N content at stage R6 and N at stage R6.7 ($r = 0.547^{*}$ and $r = 0.448^{***}$, respectively). On the other hand, N content of the leaves at stage R6 was correlated with the N content of the beans ($r = 0.504^{*}$; Figure 12).

In the case of P, the situation in "time of application" R5.5-6 is similar as compared with that pointed out before for time of application R4-5. There is a significant correlation between P content in the leaves at stage R5.5 and P at stage R6.7, which in turn correlate with the amount of P in the beans ($r = 0.464^{***}$ and 0.486^{*}, respectively; Figure 13).

These relationships show again that the initial increase of N and P contents in the leaves due to the foliar applications during stage R5.5-6 was maintained through the later stages of development until R6.7. In the case of P, this increase was also apparent in the P content of the beans. For the latest time of application (R6-6.5), yield was significantly correlated with the S content of the beans ($r = 0.696^{**}$; Figure 14). This shows that even after application of fertilizer late in the season there was still an effect which resulted in higher yields.

Figure 11. Relationship between the P and S contents in the beans with soybean yields after the plants were sprayed with fertilizer solutions during stage R5.5-6, 1974 experiment



% TOTAL S IN BEANS
0.250
0.275
0.300
0.325
0.350
SOYBEAN YIELDS ton/ha
2.80
2.70
2.60
2.50
2.40
2 30
2.20
P=1034+1437x
r=0.441*
S=1344+3962x
r=0.522*
=S
=P
0.95
1.00
1.05
1.10
1.15
% P IN THE LEAVES AT STAGE R-60

Figure 12. Relationship between the N content in the leaves at stage R6 with the N content in the beans after the plants were sprayed with fertilizer solutions during stage R5.5-6, 1974 experiment

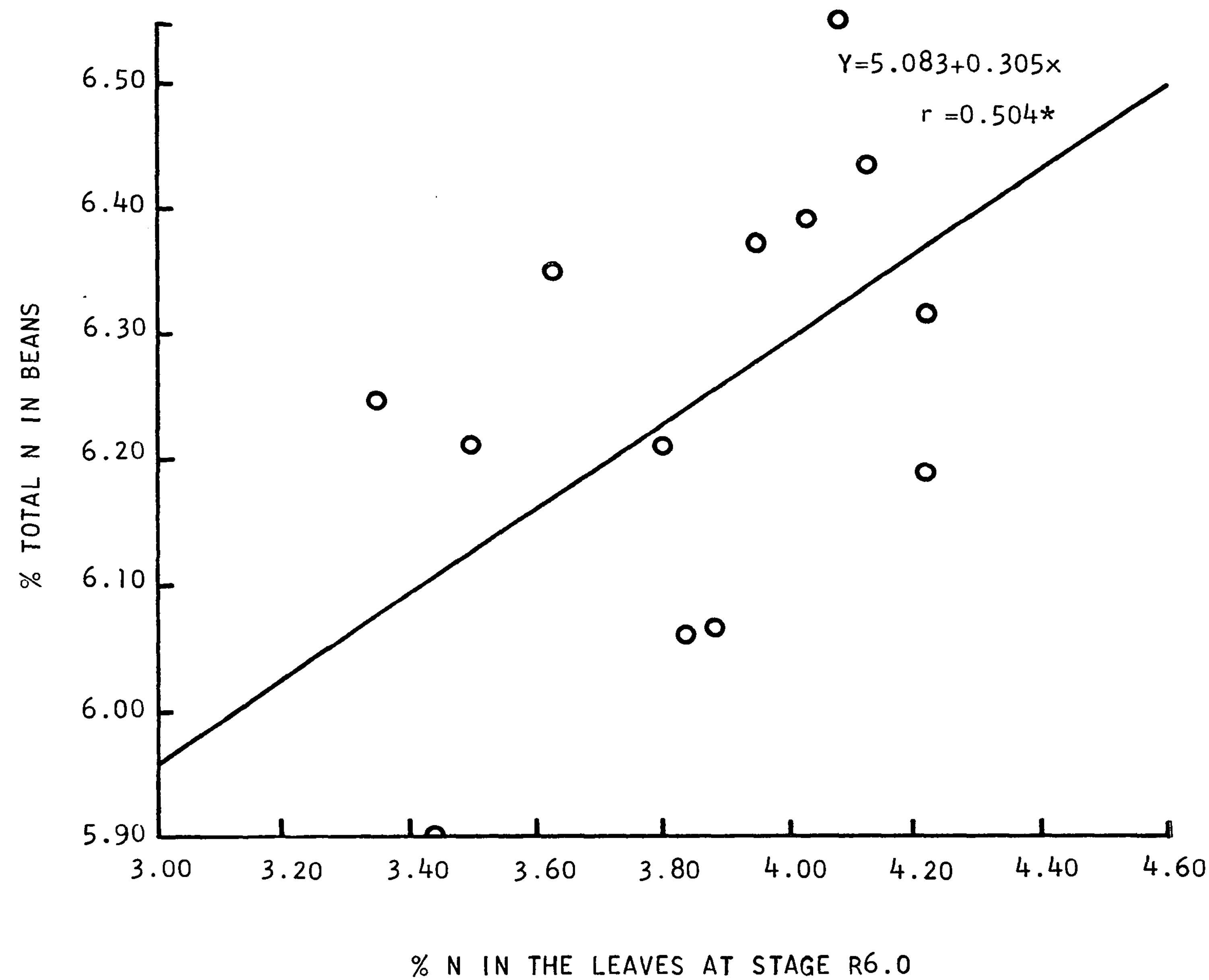

Y=5.083+0.305x
r =0.504*
6.50
6.40
6.30
6.20
6.10
6.00
5.90
% TOTAL N IN BEANS
3.00
3.20
3.40
3.60
3.80
4.00
4.20
4.40
4.60
% N IN THE LEAVES AT STAGE R6.0

Figure 13. Relationship between the P content in the leaves at stage R6.7 with the P content in the beans after the plants were sprayed with fertilizer solutions during stage R5.5-6, 1974 experiment

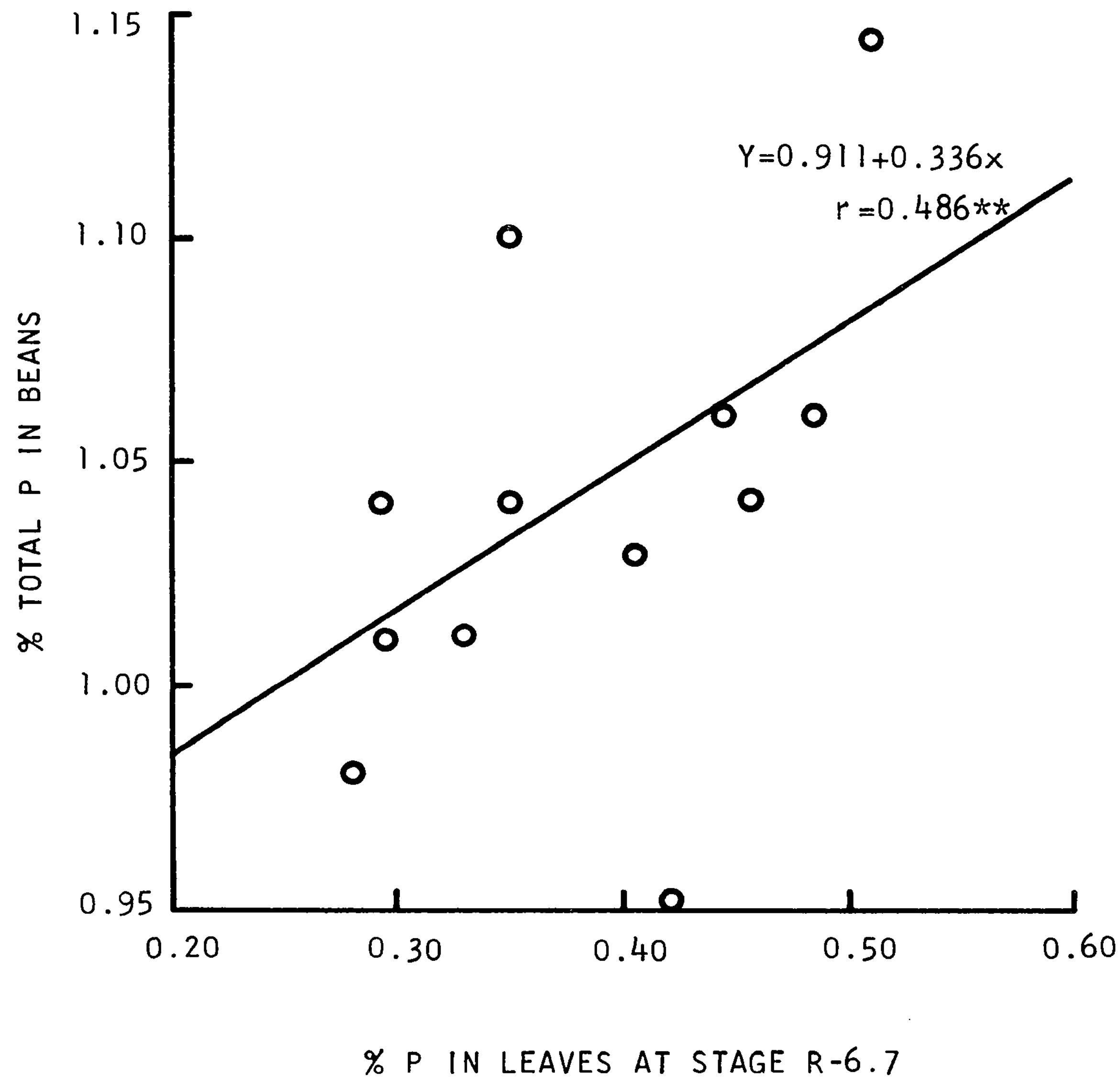
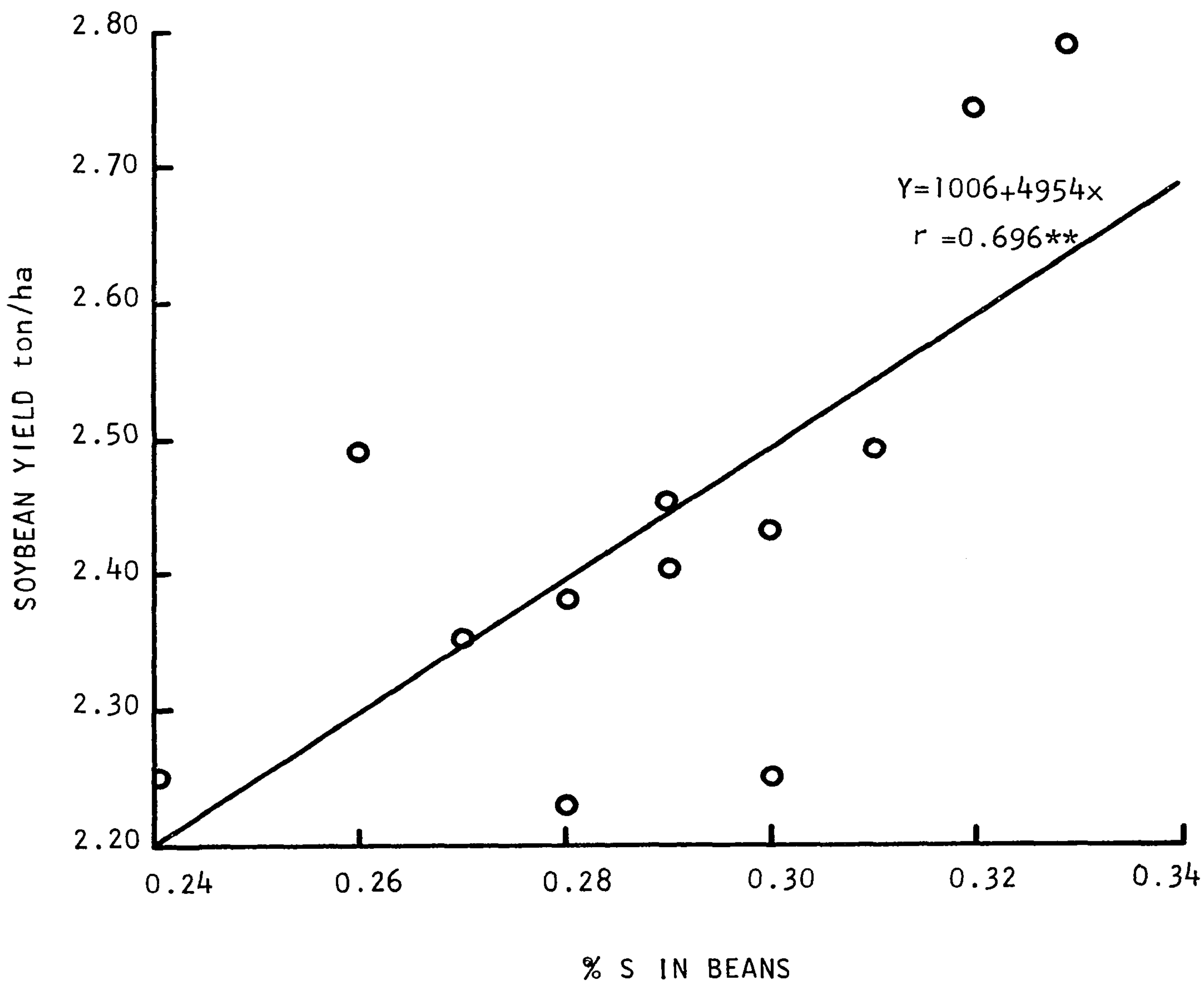

Y=0.911+0.336x
r =0.486**
% TOTAL P IN BEANS
1.15
1.10
1.05
1.00
0.95
0.20
0.30
0.40
0.50
0.60
% P IN LEAVES AT STAGE R-6.7

Figure 14. Relationship between the S content in beans with soybean yields, after the plants were sprayed with fertilizer solutions during stage R6-6.5, 1974 experiment


SOYBEAN YIELD ton/ha
2.80
2.70
2.60
2.50
2.40
2.30
2.20
0.24
0.26
0.28
0.30
0.32
0.34
% S IN BEANS
Y=1006+4954x
r =0.696**

3. Seed size

Table 10 shows the weight of 100 seeds obtained under different treatment combinations. It can be observed that in either of the 3 times of application the values for the checks are significantly higher than any other treatment and particularly higher than treatment 6. As pointed out before, treatment 6 gave the highest yield of soybeans.

Table 10. Weight of 100 seeds, 1974 experiment

Foliar treatment	Trt. no.	Weight of 100 seeds (grams)[a] Time of foliar application R4-5	R5-6	R6-6.5	Average
Check	1	17.2 a	18.4 a	16.8 a	17.5 a
34-0-0-0	2	15.1 c	16.4 bc	15.8 b	15.8 c
34-0-0-0-150[b]	3	16.5 b	16.7 b	16.7 a	16.6 b
7-21.4-36-0	4	16.3 b	16.0 bc	15.9 b	16.1 bc
41-21.4-36-0-150	5	16.4 ab	16.7 b	16.6 a	16.6 b
49-21.4-36-9-150[b]	6	15.5 c	16.4 bc	15.8 ab	15.8 c
Average		16.2 b	16.7 a	16.4 b	

[a]Values within a column and within the last row not followed by the same letter differ significantly at the 5% level.

[b]Spray solution contained sucrose at a rate of 150 kg/ha.

The apparent contradiction that higher yields were obtained with treatments that gave the lowest values for "weight of 100 seeds" can be explained by the fact that due to the effect of the foliar fertilization (and particularly treatment no. 6), all the beans in the pods had the chance to grow to a certain size and consequently could be gathered during threshing. Further evidence of this explanation can be seen if total harvested seed number per ha is considered. The check treatment resulted in fewer total seeds/ha compared to the fertilized treatments (Table 11).

Table 11. Foliar fertilization of soybeans, number of seeds per hectare, 1974 experiment

Foliar treatment	Trt. no.	Number of seeds/ha (factor = 10^6) — Time of foliar application R4-5	R5.5-6	R6-6.5	Average
Check	1	13.3	12.4	13.3	13.1
34-0-0-0	2	16.1	15.3	15.1	15.6
34-0-0-150[a]	3	14.8	15.8	14.8	15.0
7-21.4-36-0	4	16.1	15.3	14.3	15.3
41-21.4-36-0-150[a]	5	14.3	15.8	14.8	15.1
49-21.4-36-9-150[a]	6	15.3	17.3	17.0	16.3

[a]Spray solution contained sucrose at a rate of 150 kg/ha.

IV. EFFECT OF FOLIAR FERTILIZATION WITH N, P, K AND S, FACTORIAL EXPERIMENT 1975

A. Materials and Methods

This field experiment was conducted to study the response of soybeans to foliar fertilization with N, P, K and S, and to compare different kinds and amounts of the fertilizer nutrients and the interaction between them.

The experiment was planted on May 15 at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames on land in a soybean-corn crop sequence.

The soils in the experimental area were the same as those described before for the 1974 experiment.

A uniform application of PK fertilizer was applied at a rate of 112 kg P_2O_5/ha and 110 kg K_2O/ha over the experimental area. Soil test analyses of the area gave the following results: organic matter 3.83%, P "available"[1] 81 kg/ha, K "available"[2] 175 kg/ha, S 12.7 ppm and pH 6.46.

Corsoy cultivar was planted at the rate of 30 seeds per meter in .76 m row widths. An incomplete composite factorial design with 5 rates of application of N, P, K and S was used. This gives a total of 26 treatment combinations which were distributed in the field in 3 randomized blocks. Tables 12 and 13 show all the treatment combinations and their

---

[1]Bray method.

[2]Exchangeable potassium.

Table 12. Factorial experiment 1975 - treatment combinations

	Total nutrient application (kg/ha)			
Treatment no.	N	P	K	S
26	0	0	0	0
21	0	8	24	4
22	80	0	24	4
23	80	8	0	4
24	80	8	24	0
16	40	4	12	2
15	40	4	12	6
14	40	4	36	2
13	40	4	36	6
12	40	12	12	2
11	40	12	12	6
10	40	12	36	2
9	40	12	36	6
25	80	8	24	4
20	80	8	24	8
19	80	8	48	4
18	80	16	24	4
8	120	4	12	2
7	120	4	12	6
6	120	4	36	2
5	120	4	36	6
4	120	12	12	2
3	120	12	12	6
2	120	12	36	2
1	120	12	36	6
17	160	8	24	4

Table 13. Factorial experiment 1975 - codified doses

	Codes				
Nutrient	-2	-1	0	1	2
N	0	40	80	120	160
P	0	4	8	12	16
K	0	12	24	36	48
S	0	2	4	6	8

codification, respectively.

The size of the plots was 4 rows (0.76 m row distance) by 7.6 m (23.16 m^2).

Solutions were prepared so 250 liters contained the desired amounts of N, P, K and/or S for application to one hectare.

Because high concentration of nutrients would burn the leaves, the total amount of N, P, K and S in each treatment was divided in 2 to 5 applications depending on the treatment. Table 14 shows the number of times that each treatment was sprayed and the total amounts of urea (45-0-0), potassium polyphosphate (T.V.A. 0-26-25), ammonium polyphosphate (T.V.A. 11.3-37.2-0), ammonium sulfate (21.2-0-0-24), potassium sulfate (0-0-44-18) and potassium chloride (0-0-52) used to obtain the specific amounts of nutrients required for each treatment. The volume of water was adjusted so at any one time the volume

Table 14. Treatment combinations and amount of chemicals used for each treatment, factorial experiment 1975

Treatments kg/ha N - P - K - S	Total amounts of chemicals in kg/ha						
		Polyphosphate[a]					Time of appli- cation
	Urea	K	NH_4	$(NH_4)_2SO_4$	K_2SO_4	KCl	
120-12-36-6	266.67	107.40			30.80		5[b]
120-12-36-2	266.67	107.40			11.11	16.00	5
120-12-12-6	246.19	57.97	34.63	25.00			5
120-12-12-2	253.12	33.98	51.53		11.11		5
120- 4-36-6	266.65	35.71			33.33	26.01	5
120- 4-36-2	266.65	35.71			11.11	45.37	5
120- 4-12-6	258.52	35.71		17.27	10.30		5
120- 4-12-2	266.66	35.71			11.11		5
40-12-36-6	88.88	107.43			33.33		4
40-12-36-2	84.96	107.43		8.33		26.58	4
40-12-12-6	68.41	57.97	34.63	25.00			4
40-12-12-2	76.26	57.97	34.63	8.33			4
40- 4-36-6	88.88	35.71			33.33		4
40- 4-36-2	88.88	35.71			11.11	45.37	4
40- 4-12-6	77.11	35.71		25.00		8.86	4
40- 4-12-2	84.96	35.71		8.33		8.86	4
160- 8-24-4	355.54	71.42			22.22		5
80-16-24-4	165.16	115.94	18.94	16.66			5
80- 8-48-4	177.76	71.42			22.22	44.69	4
80- 8-24-8	169.35	71.42		17.87	20.61		4
0- 8-24-4		71.42			22.22		2
80- 0-24-4	177.76			16.66	22.22	27.00	4
80- 8- 0-4	157.29		50.31	16.66			5
80- 8-24-0	177.77	71.42				17.72	4
80- 8-24-4	177.77	71.42			22.22		4
0- 0- 0-0							0

[a]Specific gravity of the potassium and ammonium polyphosphates were 1.43 and 1.39 g/cm^3, respectfully.

[b]2 = R5 and R5.5; 4 = R5, 5.5, 6, and 6.5; 5 = R5, 5.5, 6, 6.5 and 6.9. Each time corresponds to 1/2, 1/4 and 1/5 of the total dose applied.

of fertilizer solution sprayed was 250 liters per hectare (1/2, 1/4 or 1/5 of the total amount of N, P, K and S applied).

Developmental stage R5 occurred on August 12, R5.5 on August 18, R6 on August 22, R6.5 on September 2 and R6.8 on September 6.

Measurable rainfall during June, July and August was 32.06 cm. Irrigation was not employed.

Fertilizer solutions were sprayed using a hand portable sprayer with a constant pressure of 30 lb/in^2 (B & G Model 7115 with adjustajet tip assembly) and following the same procedure as described for the 1974 experiment.

Samples of the youngest mature leaves were taken for each treatment at stages R5.5, R6 and R6.5. The samples were usually taken before each spray application. Plant samples were handled and analyzed for N, P and K in the same way as the 1974 experiment described previously. In addition, soluble carbohydrates were determined following the procedure described by Dunphy (1972).

The experiment was harvested on October 4 by cutting at ground level the interior 4 meters of the second and third rows of each plot and threshing them in a plot thresher.

In order to estimate which portion of the plant had the greatest increase in yield due to the treatment effects, the following treatments were harvested and divided into thirds: 1, 2, 5, 9, 16, 18, 20, 22, 24 and 26. The pods from the top, middle and bottom part of the plants were weighed separately for each treatment.

Soybean samples were taken from each treatment and ground in a Wiley Mill using a 40-mesh screen. N, P and K analyses were run following the same procedure described before. In addition to these analyses, oil analyses were run in the following treatments: 4, 5, 12, 13, 17, 18, 20, 21, 22, 23, 24, 25 and 26 at the U.S. Regional Soybean Laboratory in Urbana, Illinois (Table 45, Appendix). The weight of 100 seeds was measured for each treatment by taking a random sample of seeds from each plot.

B. Results and Discussion

1. Yield response to foliar fertilization

Table 15 shows the yields obtained for the 26 treatment combinations and the increase or decrease in yield compared against the check plot.

There was a significant effect due to treatments. The maximum yield obtained was 4.024 tons/ha and the yield of the unsprayed plots was 2.980 tons/ha.

The analysis of variance for the variable yield appears in Table 16.

Interpretation of the results obtained from the incomplete factorial design is complicated by the fact that in order to obtain different levels and ratios of the individual nutrient elements it was necessary to use different materials as sources of elements. These different sources of nutrients probably

Table 15. Effects on soybean yields of foliar applications of different nutrient solutions applied between plant developmental stages R5 and R7

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Yield ton/ha	Yield increase[a] kg/ha	
26	0	0	0	0	2.980		hi
21	0	8	24	4	2.809	-170	i
22	80	0	24	4	3.092	110	defghi
23	80	8	0	4	2.838	-140	i
24	80	8	24	0	3.292	320	bcdefg
16	40	4	12	2	2.999	-40	fghi
15	40	4	12	6	2.863	-120	i
14	40	4	36	2	3.398	420	bc
13	40	4	36	6	3.352	370	bcd
12	40	12	12	2	3.250	270	cdefgh
11	40	12	12	6	2.934	-50	i
10	40	12	36	2	2.955	-20	hi
9	40	12	36	6	3.021	40	efghi
25	80	8	24	4	3.549	570	bc
20	80	8	24	8	4.024	1040	a
19	80	8	48	4	3.085	100	defghi
18	80	16	24	4	3.621	640	b
8	120	4	12	2	2.967	-13	ghi
7	120	4	12	6	3.021	40	efghi
6	120	4	36	2	2.858	-120	i
5	120	4	36	6	2.948	-30	hi
4	120	12	12	2	3.343	360	bcde
3	120	12	12	6	3.310	330	bcdef
2	120	12	36	2	3.144	160	defghi
1	120	12	36	6	3.224	240	cdefg
17	160	8	24	4	2.960	-20	hi

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

Table 16. Analysis of variance for the variable yield, factorial experiment 1975

Source	df	SS	MS	F value	Prob > F
Blocks	2	.3114963	.15574		
Treatments	25	6.040302	.241612	7.69351**	.0001
Blocks x treatment	50	1.57023	.031404		
Total	77	7.92203	.102883		

**Significant at the 1/1000 level.

influenced the plants differently and resulted in interactions which might have affected the responses obtained from different levels and ratios of the nutrients. However, using the incomplete factorial design it was possible to quantify the values of the interactions between nutrients and to calculate an equation for yield as a function of the different elements. The equation included 19 variables representing linear and quadratic functions for each of the four nutrients applied plus all possible interactions between the linear functions (Table 17). Using the 78 observations (26 treatments and 3 replicates) obtained in the experiment, the equation explained 60% of the variation in yield ($R^2 = 0.602$).

Using this equation it was possible to calculate separate yield response curves for the four nutrients and their optimum level of application. Figures 15, 16 and 17 show the response

Table 17. Regression equation for estimating soybean yield response to rates of application of N, P, K and S

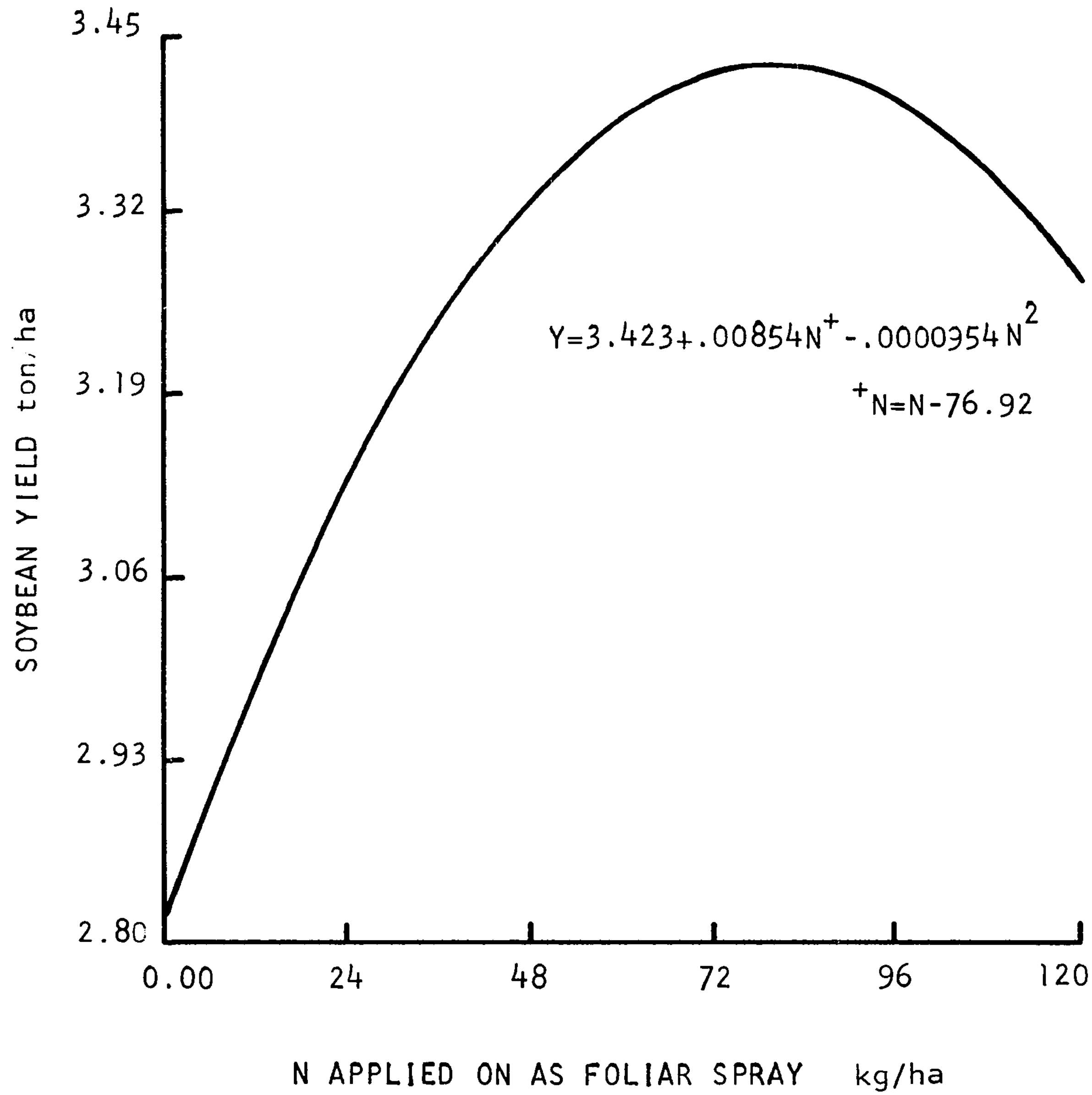
Variable	Coefficients	t values	Prob t	R^2	F	Prob F
				0.602**	4.63	0.0001
Intercept	3.412	28.13	0.0001**			
N	0.000659	0.94	0.64			
P	0.0186	2.66	0.009**			
K	0.00437	1.87	0.06*			
S	0.0167	1.19	0.23			
N^2	-0.000095	-4.12	0.0003**			
P^2	-0.00217	-0.93	0.64			
K^2	-0.000926	-3.60	0.001**			
S^2	-0.01017	1.09	0.27			
NP	0.000711	3.42	0.0015**			
NK	-0.000127	-1.84	0.06*			
NS	0.00677	1.63	0.10***			
PK	-0.00141	-2.04	0.04*			
PS	0.000218	0.052	0.95			
KS	0.00218	1.57	0.11***			
NPK	0.000020	1.23	0.21			
NPS	-0.000076	-0.76	0.54			
NKS	-0.000044	-1.35	0.17			
PKS	0.0000026	0.08	0.98			
NPKS	0.0000072	1.00	0.32			

**Significant at 1% level.

*Significant at 5% level.

***Significant at 10% level.

Figure 15. Response curve to N applied as a foliar spray during the seed-filling period, values for P, K, and S added were held constant at 8, 24 and 4 kg/ha, respectively, factorial experiment 1975



SOYBEAN YIELD ton/ha
3.45
3.32
3.19
3.06
2.93
2.80
0.00
24
48
72
96
120
Y=3.423+.00854N+-.0000954N2
+N=N-76.92
N APPLIED ON AS FOLIAR SPRAY kg/ha

Figure 16. Response curve to P applied as a foliar spray during the seed-filling period, values for N, K and S were held constant at 80, 24, and 4 kg/ha, respectively, factorial experiment 1975

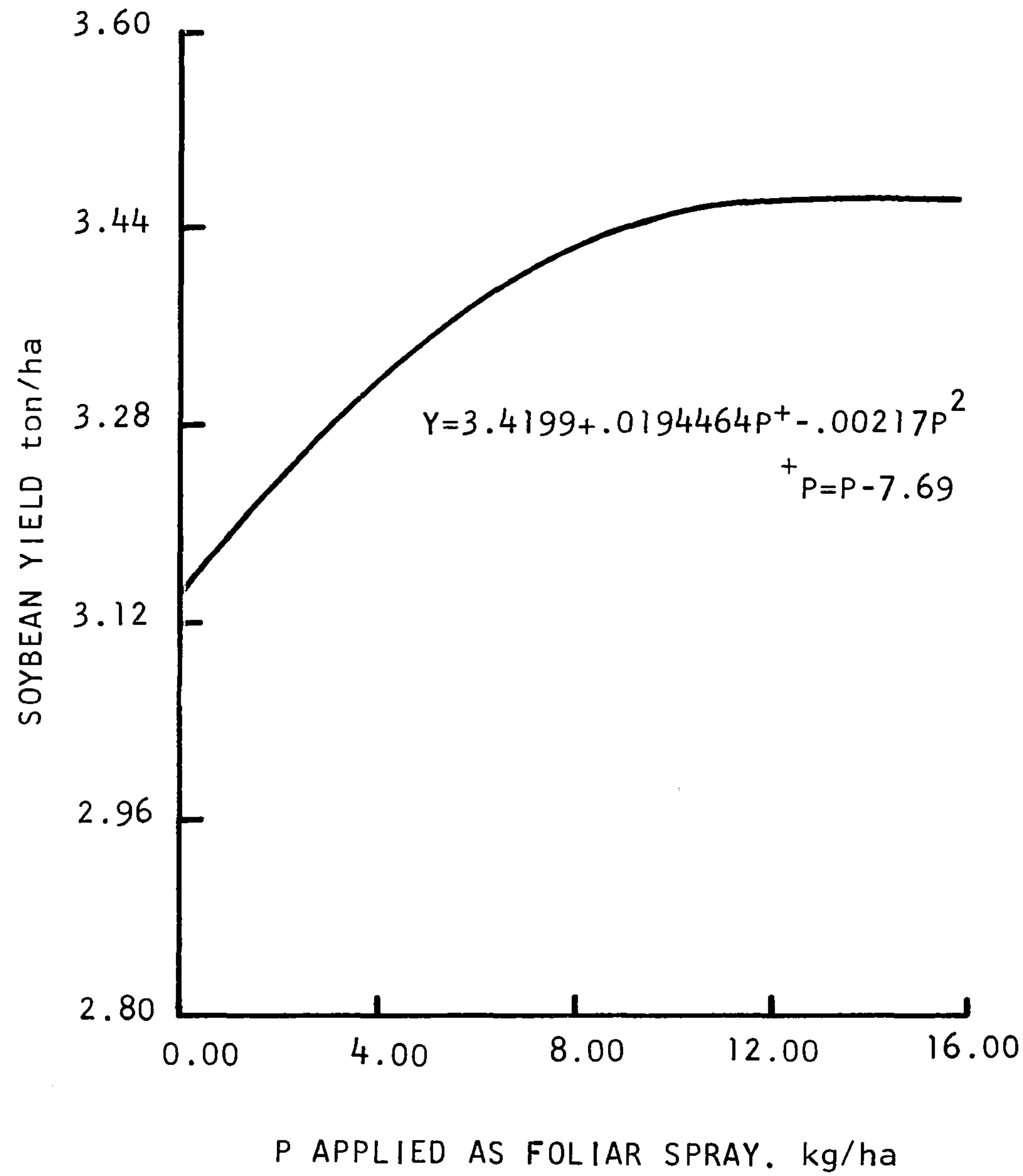
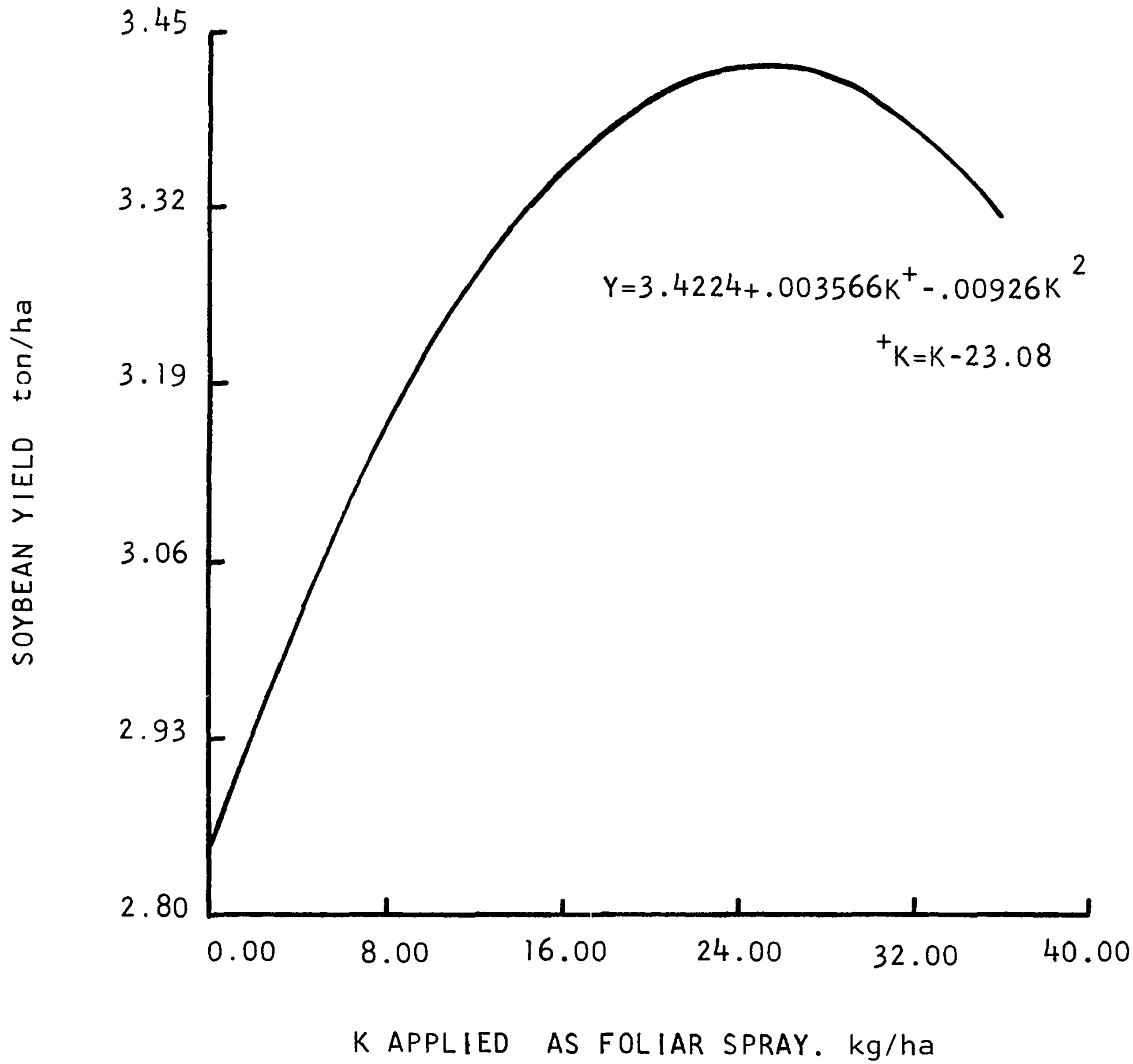

SOYBEAN YIELD ton/ha
3.60
3.44
3.28
3.12
2.96
2.80
0.00
4.00
8.00
12.00
16.00
Y=3.4199+.0194464P+-.00217P2
+P=P-7.69
P APPLIED AS FOLIAR SPRAY. kg/ha

Figure 17. Response curve to K applied as a foliar spray during the seed-filling period, values for N, P, and S were held constant at 80, 8, and 4 kg/ha, respectively, factorial experiment 1975



3.45
3.32
3.19
3.06
2.93
2.80
SOYBEAN YIELD ton/ha
Y=3.4224+.003566K+-.00926K 2
+K=K-23.08
0.00
8.00
16.00
24.00
32.00
40.00
K APPLIED AS FOLIAR SPRAY. kg/ha

curves for N, P and K. The computed rates of N, P, K and S from which the maximum yield was obtained was 81.4 kg/ha for N, 12.7 kg/ha for P, 26.9 kg/ha for K, and 4.85 kg/ha for S.

Foliar applications of solutions that contained only three of the four nutrient elements resulted in small or no increase in soybean yields. Where N, P or K was not included in the foliar spray, there was no increase in yield. Where the spray solution contained N, P and K but not S, there was a significant yield increase of 320 kg/ha over the check.

Applications of solutions containing all four nutrients in varying amounts and ratios increased yields as the amount of N applied increased from 0 to 80 kg/ha, but then decreased yields as the amount of N increased from 80 to 160 kg/ha (Table 18).

In spite of the fact that the yields in Table 19 differ significantly as the amount of N applied increases, it is not possible to establish a valid comparison between them due to the fact that the rates of P, K and S do not remain constant. In order to permit this comparison, Table 19 shows 3 treatments in which the rates of P, K and S are held constant and only the N applied varies.

Application of 80-8-24-8 kg of N-P-K-S/ha increased yield by 1040 kg/ha. Where the amount of S was reduced from 8 to 4 kg/ha the yield increase was 570 kg/ha. This might indicate that 4 kg S/ha was not adequate for optimum yield. However, in other comparisons where N, P, and K were held constant and S was increased from 2 to 6 kg/ha, the increased S application

Table 18. Effect on soybean yield of increasing doses of N and P, K, S in varying amounts applied as a foliar spray

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Yield[a] ton/ha
21	0	8	24	4	2.809 d
11	40	12	36	6	3.021 cd
25	80	8	24	4	3.549 b
20	80	8	24	8	4.024 a
1	120	12	36	6	3.224 c
17	160	8	24	4	2.960 cd

[a]Values not followed by the same letter differ significantly at the 5% level.

Table 19. Effect on soybean yield of increasing doses of N at a constant application of P, K and S

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Yield[a] ton/ha
21	0	8	24	4	2.809 d
25	80	8	24	4	3.549 b
17	160	8	24	4	2.960 cd

[a]Values not followed by the same letter differ significantly at the 5% level.

did not result in increased yield (Table 15). Actually, comparing treatments 11 and 12, there was a decrease in yield resulting from increasing the amount of S from 2 to 6 kg S/ha. It is necessary to point out that this decreasing effect shows up only where the ratio between P and K added was 1 (treatments 11, 12). Where the K added was greater than P there was no such effect (treatments 1, 2; 5, 6; 7, 8; 13, 14; 15, 16). This would suggest that there must be an optimum ratio between P and K at a constant level of N that has a direct effect on the response of the plant to nitrogen. Where the amount of N was 120 kg/ha, rather than 40 kg/ha, a decreasing effect of S did not result when the ratio of P to K added was 1 (treatments 2 and 3). Table 20 shows the effect of increasing the rates of N from 40 to 120 kg/ha at two levels of P (4 and 12 kg/ha) and 36 and 6 kg/ha of K and S, respectively. The effect was significantly detrimental in the first situation (4 kg/ha P) and there was no significant effect in the second case (Table 20).

Comparing with the check plot, no yield increase resulted from the one treatment with an NPKS solution applied at the rate of 160 kg/N/ha. Applications with N applied at 120 kg/ha resulted in yield increases of 160 to 360 kg/ha where the application included P at the rate of 12 kg/ha (N:P=10:1), but no increase in yield where only 4 kg/P/ha was applied (N:P= 30:1). Applications with the N applied at 40 kg/ha resulted in yield increases of 370 to 420 kg/ha over the check plot

Table 20. Effect on soybean yield of increasing doses N at varying amounts of P, K and S applied as a foliar spray

	Total nutrient application (kg/ha)				
Trt. no.	N	P	K	S	Yield[a] ton/ha
13	40	4	36	6	3.352 a
5	120	4	36	6	2.948 b
9	40	12	36	6	3.021 b
1	120	12	36	6	3.224 ab

[a]Values not followed by the same letter differ significantly at the 5% level.

where the application included P at 4 kg/ha (N:P=10:1) and K at 36 kg/ha.

There was a significant effect due to P fertilization (Table 15). Increasing the rate of P from 4 to 12 kg P/ha at a constant level of 40, 36 and 6 kg/ha of N, K and S, respectively, did not increase yield significantly (Table 21). When the same comparison was done at a level of 120, 36 and 6 kg/ha of N, K and S, there was a significant effect of P on yields (Table 21). Increasing the amount of P from 0 to 8 kg/ha had a significant effect on yield when the levels of N, K and S were held at 80, 24 and 4 kg/ha, respectively (Table 22). It is also important to point out that the treatment which included the combination of 80-8-24-4 kg/ha of N, P, K and S, respectively, produced significantly higher yields than

Table 21. Effect on soybean yield of increasing doses of P at varying amounts of N, K and S applied as foliar spray

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Yield[a] ton/ha
13	40	4	36	6	3.352 a
9	40	12	36	6	3.021 bc
5	120	4	36	6	2.948 cd
1	120	12	36	6	3.224 ab

[a]Values not followed by the same letter differ significantly at the 5% level.

Table 22. Effect on soybean yield of increasing doses of P at a constant application of N, K and S

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Yield[a] ton/ha
22	80	0	24	4	3.092 b
25	80	8	24	4	3.549 a
18	80	16	24	4	3.621 a

[a]Values not followed by the same letter differ significantly at the 5% level.

the other treatments in Table 21 even though the amount of N and K in 2 of them are higher (120 and 36 kg/ha of N, respectively). The only exception to this was treatment no. 13 (40-4-36-6 kg of N, P, K and S/ha) which is not significantly different.

Increasing the amount of P from 8 to 16 kg/ha did not result in a significant additional yield increase (Table 22).

There was a significant effect due to K fertilization (Table 15). Increasing the amount of K from 12 to 36 kg/ha at a constant level of N, P and S (40-4-6 kg/ha, respectively) produced a significant yield increase (489 kg/ha) (Table 23). On the other hand, the same increase of K at a higher level of N (120 kg/ha) did not produce significant changes in yield (Table 23). This would mean that there must be an optimum ratio of N, P, K and S under which it is possible to attain a maximum yield increase.

Table 24 shows that the biggest increase in yield was obtained (711 kg/ha) when the amount of K also increased from 0 to 24 kg/ha and N, P and S are held constant at 80-8-4 kg/ha, respectively. Where the amount of K was increased from 24 to 48 kg/ha, there were no effects on yield due to the foliar application (Table 24).

It can be concluded from the results obtained that the treatments which gave the highest yields were the ones in which N, P, K and S are approximately in the ratio of 10:1:3:0.5, respectively (treatments 1, 3, 4, 18, 20, 25, 13). Nagymihaly

Table 23. Effect on soybean yield of increasing doses of K at varying amounts of N, P and S applied as a foliar spray

	Total nutrient application (kg/ha)				
Trt. no.	N	P	K	S	Yield[a] ton/ha
15	40	4	12	6	2.863 b
13	40	4	36	6	3.352 a
7	120	4	12	6	3.021 b
5	120	4	36	6	2.948 b

[a]Values not followed by the same letter differ significantly at the 5% level.

Table 24. Effect on soybean yield of increasing rates of K at a constant application of N, P and S

	Total nutrient application (kg/ha)				
Trt. no.	N	P	K	S	Yield[a] ton/ha
23	80	8	0	4	2.838 b
25	80	8	24	4	3.549 a
19	80	8	48	4	3.085 b

[a]Values not followed by the same letter differ significantly at the 5% level.

et al. (1954), Kuthy et al. (1952), Thorne (1955a,b), Milica (1959) and Milojic (1957) also reported increases in yields up to 40% in sugar beets after spraying them with a complete solution of NPK. Working with small grains, Chumakov and Bystrova (1958), Narayanan and Vasudevan (1957), Davidescue (1960a) and Von Boguslawski and Vomel (1957) obtained the same kind of results.

Several authors (Sita Ram and Abraham, 1970; Polgar, 1962; Thomas, 1960; Galgoczi, 1967) reported substantial increases on yield due to complete foliar fertilization in cotton, rice, corn, clover and sunflower.

Hanway (1975) reported that late in the growing season as the pods and seeds develop, translocation of N, P, K and S to these developing parts result in decreased content of these elements in all the vegetative plant parts. This depletion contributes to the senescense of the leaves and accordingly they turn yellow and fall.

Lawn and Brun (1974) demonstrated that the symbiotic nitrogen fixing capacity declines markedly during the early pod-filling stage of development. Thibodeau and Jaworski (1975) showed that the nitrogen fixation bore a reciprocal relationship to that of nitrate reductase. These authors (Thibodeau and Jaworski, 1975) determined that the maximum level of nitrogen fixation was obtained at early pod fill when nitrate reductase activity had dropped to 25% of the maximum. A rapid loss of nitrogen fixation activity occurred shortly after bean et al. (1954), Kuthy et al. (1952), Thorne (1955a,b), Milica (1959) and Milojic (1957) also reported increases in yields up to 40% in sugar beets after spraying them with a complete solution of NPK. Working with small grains, Chumakov and Bystrova (1958), Narayanan and Vasudevan (1957), Davidescue (1960a) and Von Bogularoski (1957) obtained the same kind of results.

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Sinclair and de Wit (1975) estimated that the N requirement for the soybean seeds was 29 mg of N per gram of photosynthate produced. This value compared with other crops is so great that a sustained seed growth demands a continued nitrogen translocation from vegetative tissues. In the case of the rest of the nutrients the situation is quite similar, with the difference being that P then must be taken up by the roots. It has been reported by Bloomquist and Kust (1971) that late in the growing season the roots stop or decline to absorb actively nutrients from the soil, possibly due to the lack of supply of photosynthetic assimilates. Hume and Criswell (1972) reported that only very small amounts of C^{14} have been recovered from the roots and nodules after pod filling commences. The foliar spray with an NPKS solution during this period should minimize this nutrient depletion of the leaves so photosynthesis in the leaves will be maintained at a higher level resulting in increased seed yields. The fact that all four of these nutrient elements normally are depleted in the leaves and that the foliar spray to be most effective must supply all four of the elements in the proportions found in the seeds explains why foliar sprays that supplied only one or two of the elements during the seed-filling period were not very effective (Barel, 1975; Chesnin and Shafer, 1953; Mederski and Volk, 1956).

2. Chemical analysis of leaves and grain

Table 25 shows the N, P and K content of the leaves and grain at different stages of development (R5.5, R6, R6.5) in 17 of the 26 treatment combinations.

In order to detect possible effects due to treatments, an analysis of variance was calculated for each nutrient content in the leaves at 3 different stages of development and in the grain at harvest.

In spite of the fact that the values for N, P and K in the leaves decrease with time, the treatment means are significantly different at each one of the 3 stages of development sampled with the exception of K at stage R6.5.

The N content of the leaves from the check plot was the lowest at each one of the 3 stages of development. At sampling time R5.5, the highest value obtained was 3.70% N found for treatment 22 (80-0-24-4 kg/ha of N, P, K and S, respectively). There was no clear relationship between the amount of N added as a foliar spray and the N content of the leaves at this stage of development, but in general it can be said that the pattern tends to show lower values for the checks and higher

Table 25. N, P, K and protein content in leaves and grain at different stages of development, factorial experiment, 1975

Trt. no.	N	P	K	S	Nutrient content of leaves[a] % N Stage of development R5.5	R6	R6.5
26	0	0	0	0	2.89 ef	2.17 c	1.51 c
21	0	8	24	4	3.23 bcde	2.05 c	1.53 ab
22	80	0	24	4	3.17 a	2.84 ab	2.77 ab
23	80	8	0	4	2.70 f	2.40 bc	2.40 ab
24	80	8	24	0	3.20 bcde	2.76 ab	2.55 abc
15	40	4	12	6	2.67 a	2.77 ab	2.63 ab
13	40	4	36	6	3.15 cdf	2.70 ab	2.15 b
11	40	12	12	6	3.42 bcde	2.94 a	2.45 ab
9	40	12	36	6	3.18 bcde	2.79 ab	2.16 b
25	80	8	24	4	3.55 abc	2.76 ab	2.69 abc
20	80	8	24	8	3.38 bcd	2.84 ab	2.44 ab
19	80	8	48	4	3.58 ab	2.84 ab	2.85 a
18	80	16	24	4	3.23 bcde	2.52 abc	2.45 ab
7	120	4	12	6	3.18 bcde	2.52 abc	2.42 ab
5	120	4	36	6	3.07 def	2.48 abc	2.31 ab
1	120	12	36	6	3.11 def	2.66 ab	2.40 ab
17	160	8	24	4	3.55 abc	2.82 ab	2.93 a

[a]Values within a column followed by the same letter do not differ significantly at 5% level.

Nutrient content of leaves					
% P			% K		
Stage of development			Stage of development		
R5.5	R6	R 6.5	R5.5	R6	R6.5
.185 h	.137 e	.134 f	.75 cde	.62 c	.67
.311 a	.258 ab	.316 a	.93 abc	.83 bc	.70
.223 fg	.181 de	.149 f	.86 abcd	.92 b	.70
.219 fg	.236 abcd	.260 abc	.68 c	.76 bc	.55
.290 abc	.267 ab	.262 abcd	.94 ab	.90 b	.61
.287 abc	.236 abcd	.297 ab	.96 a	.64 c	.67
.210 fgh	.214 bcd	.230 bcd	.73 de	.68 ab	.70
.239 ef	.241 abc	.296 ab	.93 abc	.80 bc	.54
.220 fg	.231 abcd	.272 ab	.75 cde	.73 bc	.57
.266 cd	.238 abcd	.206 def	.87 abcde	.73 bcd	.76
.264 cde	.267 ab	.272 ab	.94 ab	.91 b	.80
.278 bcd	.271 ab	.274 ab	.92 abc	.69 bc	.71
.305 ab	.281 a	.329 a	.98 abcd	.65 c	.61
.195 gh	.222 bcd	.186 cd	.87 abcde	1.13 a	.65
.199 gh	.186 de	.167 d	.83 abcde	.65 c	.56
.237 ef	.221 bcd	.267 abc	.90 abcd	.76 bc	.63
.255 de	.217 bcd	.256 abc	.93 ab	.61 c	.74

Table 25. (Continued)

Trt. no.	N	P	K	S	Nutrient content of the grain % N	% P	% K	% protein
26	0	0	0	0	6.17 cd	.497	2.12	38.56 cd
21	0	8	24	4	6.35 bcd	.571	2.12	39.69 bcd
22	80	0	24	4	6.76 abcd	.507	2.11	42.25 abcd
23	80	8	0	4	6.68 abde	.497	2.07	41.75 abcd
24	80	8	24	0	6.55 abcd	.497	2.08	40.94 abcd
15	40	4	12	6	7.00 ab	.536	2.10	43.75 ab
13	40	4	36	6	6.95 ab	.529	2.15	43.44 ab
11	40	12	12	6	6.88 abc	.513	2.13	43.00 abc
9	40	12	36	6	6.78 abcd	.503	2.10	42.25 abcd
25	80	8	24	4	6.64 abcd	.513	2.09	41.50 abcd
20	80	8	24	8	6.80 abc	.545	2.07	42.50 abc
19	80	8	48	4	6.72 abcd	.513	2.11	42.00 abcd
18	80	16	24	4	6.70 abcd	.538	2.15	41.88 abcd
7	120	4	12	6	6.86 abc	.481	2.10	42.88 abcd
5	120	4	36	6	6.59 abcd	.476	2.12	41.19 abcd
1	120	12	36	6	6.12 e	.537	1.98	38.25 e
17	160	8	24	4	6.75 abcd	.491	2.03	42.19 abcd

values for the treatments that received foliar fertilization (Table 25). One possible explanation of this is that at this stage of development (R5.5) only 1/4 of the total dose of N was applied; therefore, this amount permitted only significant differences to be apparent between the check plots and the rest of the treatments.

At stage of development R6 the lowest values for N in the leaves again were found in leaves from the check plots. The N content for treatment 26 (0-0-0-0 kg N, P, K, S/ha) and 21 (0-80-24-4 kg/ha N, P, K, S) were 2.17% and 2.05%, respectively. The rest of the treatments show N contents which do not differ very much (Table 25). In spite of this there was a positive significant correlation (r=0.246**) between the amount of N added as foliar fertilization and the amount of N in the leaves at this stage of development.

Nevertheless, it is interesting to note that while the N content of the leaves from the check plots at stage R6 decreased an average of .94 when compared with stage R5.5, whereas the average decrease for the rest of the treatments was only .49.

At stage of development R6.5, the N content of the leaves from the check plots was almost 1% lower than the rest of the treatments (1.52% compared with 2.51%). The highest value of N obtained was 2.93%, which was for treatment 17 (160-8-24-4 kg/ha of N, P, K, S), which was the treatment with the highest amount of N applied.

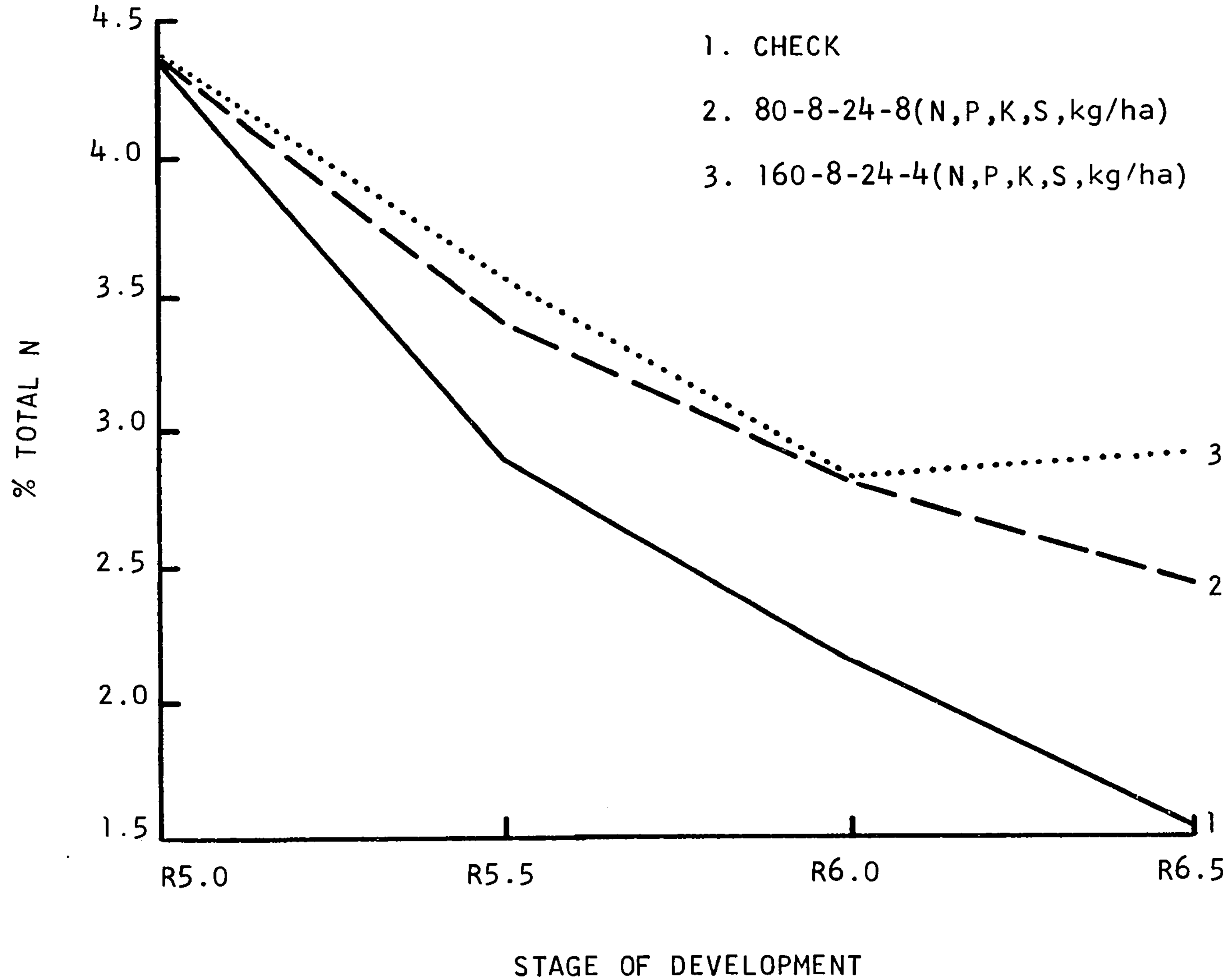
There was a negative relationship between the decrease in the N content of the leaves between stages R6 and R6.5 and the amount of N applied as foliar fertilization. The average decrease of the N content of the leaves in the check plot was .59% (from 2.11% at R6 to 1.52% at R6.5). However, this decrease was only .12% where an average of 80 kg/ha of N was applied. (This decrease in % N was calculated by taking the average of all the treatments which had this amount applied.) The same procedure of calculation was used for the treatments which received 40 and 120 kg/ha of N, respectively. The decrease in these two cases was .45% N and .18% N.

It is worth pointing out that when 160 kg/ha was applied the N content of the leaves at stage R6.5 was increased by .11% (from 2.82% at stage R6 to 2.93% at stage R6.5). Figure 18 compares the decrease in N content of the leaves with time for 3 different foliar treatments: 0, 80 and 160 kg/N/ha, respectively. There was a positive correlation between the N content at this stage of development and N added as a foliar fertilizer ($r=0.285^{**}$).

The N content of the beans varied from 6.12% to 7.00%. In general, this content was high for the treatments in which N was applied as a foliar spray, but it does not follow a clear pattern in this respect.

With the exception of the check plot, there is an increase in the P content of the leaves with time. At each stage of development at which samples were taken, the P content of the leaves from the check plots were significantly

Figure 18. Variation of the N content in the leaves with time under different foliar spray treatments applied during stages R5 through R6.5, factorial experiment 1975


1. CHECK
2. 80-8-24-8(N,P,K,S,kg/ha)
3. 160-8-24-4(N,P,K,S,kg/ha)
% TOTAL N
4.5
4.0
3.5
3.0
2.5
2.0
1.5
R5.0
R5.5
R6.0
R6.5
1
2
3
STAGE OF DEVELOPMENT

lower than the treatments that received 8 or more kg/ha of P (Table 25).

At sampling time R5.5 the highest value of P in the leaves was .311% found for treatment 21 (0-8-24-4 kg/ha of N, P, K, and S). This could be explained by two reasons. The first reason is that at this stage of development treatment 21 had received 1/2 of the total dose of P that was going to be applied, compared to 1/4 and 1/5 of the same dose for the rest of the treatments. Secondly, treatment 22 does not include N, so the absorption of P was probably enhanced in the absence of N. On the other hand, Mukherjee et al. (1966) and Okuda and Yamada (1962) found that the effectiveness of P sprays was greatly enhanced if urea was added to the spray solution. This could mean that the rate of translocation of the P already absorbed was diminished in the absence of N. There was a positive significant correlation between the amount of P added as a foliar spray and the concentration of P in the leaves at stage R5.5 (r=0.427**), but the P content in the leaves at this stage of development does not correlate with yields. At stage of development R6 the lowest values for P in the leaves were found for leaves from the check plots. The P contents for treatment 26 (no fertilizer added) and 22 (80-0-24-4 kg/ha of N, P, K and S) were .137 and .181%, respectively. The P in the leaves for treatments which included P as a foliar fertilization varied from .186% in treatment 4 (120-4-36-6 kg/ha of N, P, K and S) to .281% in treatment 18 (80-16-24-4 kg/ha of N, P, K and S) (Table 25). There was a positive significant correlation between P added as a foliar spray and the P content of the leaves at this stage of development (r=0.575**) which in turn correlates with yields (r=0.395*). The P content of leaves from the check plots decreased an average of .045 when stage R6 is compared with stage R5.5. On the other hand, there was an average increase of .085 in the P content of the leaves in the treatments which included P as a foliar spray when stages R6 and R5.5 are compared.

At stage of development R6.5 the P content of the check plots was .154% for treatment 26 (no fertilizer added) and .149% for treatment 22 (80-0-24-4 kg/ha of N, P, K and S). This amount was less than half the amount of P in the leaves found in treatment 18 (80-16-24-4 kg/ha of N, P, K and S) which was .329%. There is a positive correlation between the amount of P added as foliar fertilizer and the P content in the leaves at stage R6.5 (r=.395**).

With the exception of the check plots and two treatments that included 4 kg/ha of P (treatments 5, 7) the P content in the leaves was greater at stage R6.5 than at stage R6. This does not agree with what has been reported in the literature. Hanway (1975), Hanway and Weber (1971d) and Dunphy (1972) found that the P content in the leaves and petioles decreased steadily late in the growing season. The results reported here suggest that due to the foliar fertilization, and in spite of the active translocation of nutrients, it is possible to maintain or increase the P level in the leaves after stage of development R6. Figure 19 illustrates the change in P content of the leaves with time under 3 different foliar treatments: 0, 8, and 16 kg/ha of P, respectively.

There were no significant differences in the P content of the beans due to treatment effects. The analytical values for P in the seeds obtained agree with what has been reported in the literature by Hanway (1975), Hanway and Weber (1971d) and Dunphy (1972).

The percentage of K found in the leaves was low for all the treatments. The K content of the leaves decreased steadily with time. At stage of development R5.5 and R6, there are significant differences between the content of K in the leaves of the check plots and the leaves of plots that received K foliar fertilization. Nevertheless the rate of decrease in the K content of the leaves between stage R5.5 and stage R6 seems to be fairly constant for all the treatments, with the exception of treatment 7 (120-4-12-6 kg/ha of N, P, K and S) in which there was a significant increase, and treatment 20 in which there was practically no decrease (.935% at stage R5.5 and .906% at stage R6).

At stage of development R6.5 there were no significant differences in the K content of the leaves among the different treatments tested. The average value of the K content at this stage was .643%. Figure 20 shows the change in K content of

Figure 19. Variation of the P content in the leaves with time under different foliar spray treatments applied during stages R5 through R6.5, factorial experiment 1975

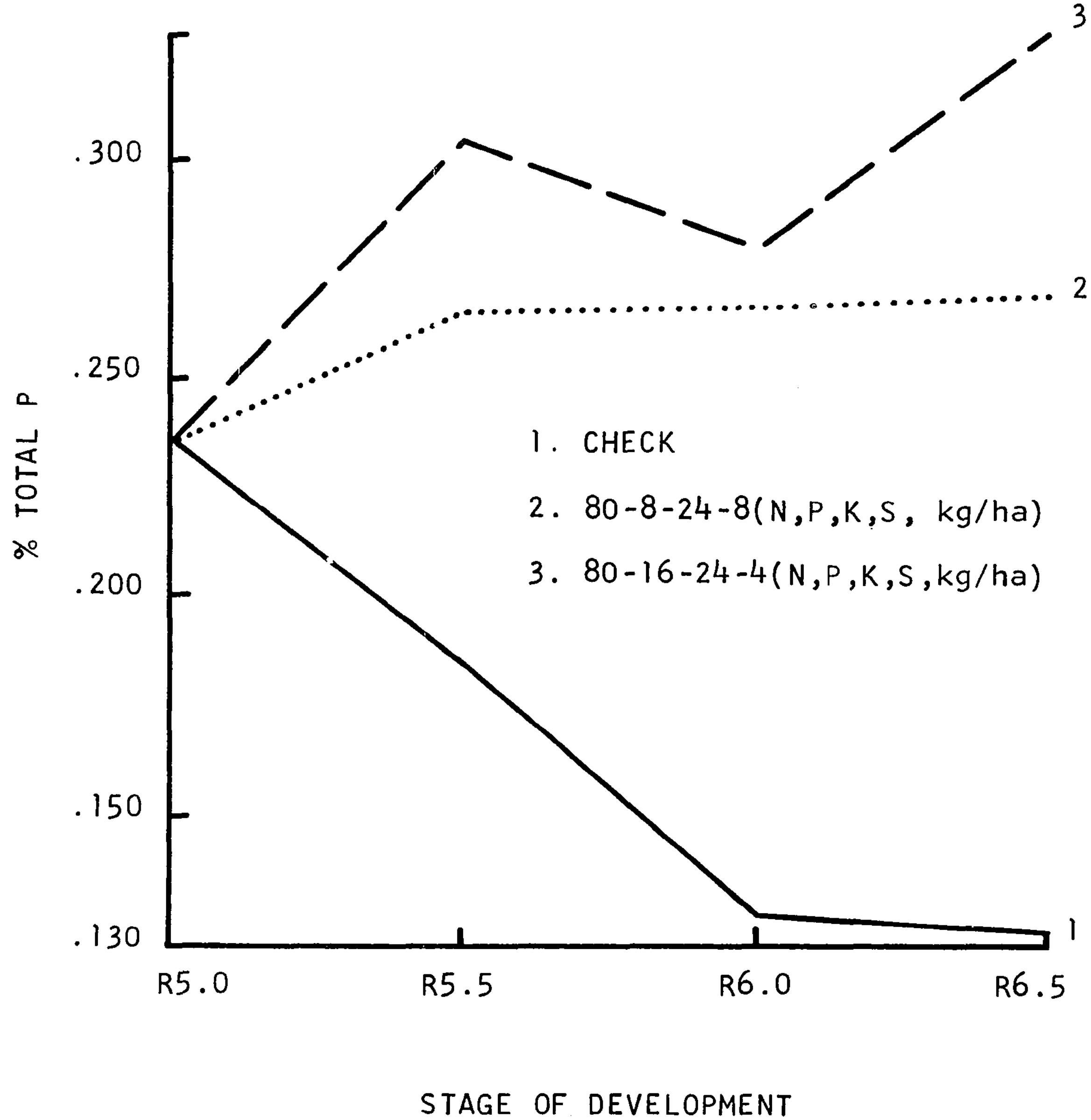
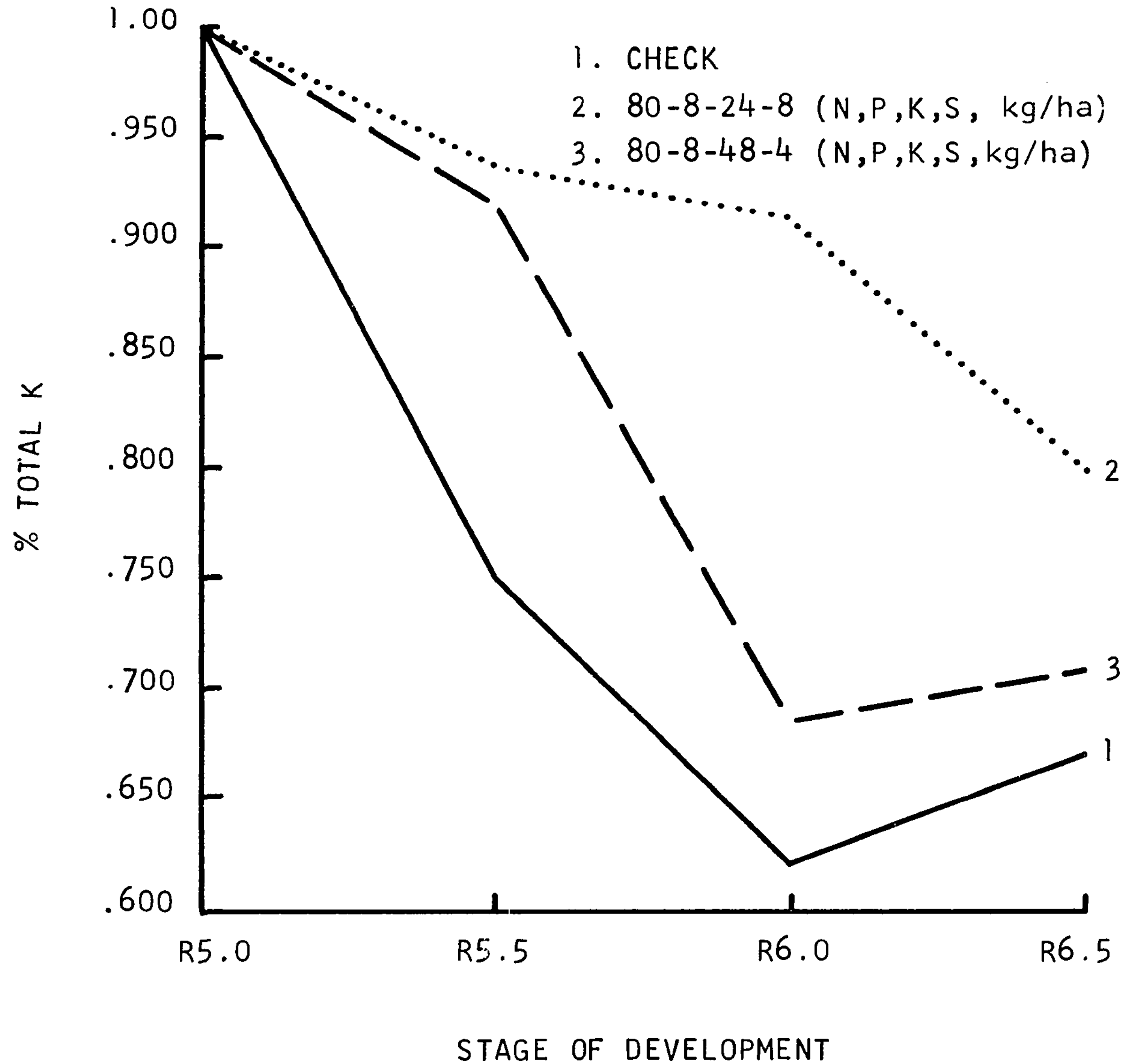

% TOTAL P
.300
.250
.200
.150
.130
R5.0
R5.5
R6.0
R6.5
STAGE OF DEVELOPMENT
1. CHECK
2. 80-8-24-8(N,P,K,S, kg/ha)
3. 80-16-24-4(N,P,K,S,kg/ha)
1
2
3

Figure 20. Variation in the K content of the leaves with time under different foliar spray treatments applied during stages R5 through R6.5, factorial experiment 1975


1.00
.950
.900
.850
.800
.750
.700
.650
.600
% TOTAL K
1. CHECK
2. 80-8-24-8 (N,P,K,S, kg/ha)
3. 80-8-48-4 (N,P,K,S,kg/ha)
2
3
1
R5.0
R5.5
R6.0
R6.5
STAGE OF DEVELOPMENT

of the leaves with time under 3 different foliar treatments: 0, 24 and 48 kg/ha of K, respectively. There was a significant correlation between the K content of the leaves at stage R6 and yield (r=0.168***). In spite of the low value for r, it gives some indication of this relationship which is important to consider, given the fact that there was an effect due to treatments on the concentration of K in the leaves at the same stage of development. There were no significant differences among treatments for the K content in the beans. The overall mean for this variable was 2.01%.

Simple linear correlations were computed between the amount of N, P, K and S added as fertilizer, the yields obtained in each treatment, the analytical values of the leaves and beans, and the weight of 100 seeds. The correlation coefficients involving the variables which had a probability of occurrence under the null hypothesis of 10% or less are summarized in Table 26.

The N added as foliar fertilizer correlates with the N content in the leaves at stages R6 (r=0.246**), R6.5 (r=0.288**), and the N and protein contents of the beans (r=0.444** and 0.446**, respectively). On the other hand, there is a negative correlation between N fertilization and the P content of the beans (r=-0.380**). As pointed out before, these results show that foliar fertilization with N increased the N content of the leaves and beans. The linear correlation between the amount of N applied and yields was not significant,

Table 26. Correlation coefficients between variables, factorial experiment 1975

	Yield	N R5.5	P R5.5	K R5.5	N R6	P R6	K R6
N kg/ha	0.370***				0.246**		
P kg/ha	0.240**			0.427***		0.575***	
K kg/ha	0.271***	0.214*					
S kg/ha	0.367***						
Yield						0.390**	0.168***
% N R5.5			0.530***	0.200*	0.328**		
% P R5.5				0.309**		0.573***	
% K R5.5					0.186*		0.181***
% N R6						0.319**	0.207*
% P R6							0.390***
% K R6							
% N R6.5							
% P R6.5							
% K R6.5							
% N beans							
% protein							
% P beans							
% K beans							
Wt./100 seeds							

***Significant at 10% level.

*Significant at 5% level.

**Significant at 1% level.

N R6.5	P R6.5	K R6.5	N beans	Protein	P beans	K beans	Wt/100 sd
0.288**			0.444***	0.446***	-0.380***		
	0.395***						
							0.248**
0.413***							
0.312**	0.482***	0.196*					
						0.350**	
0.243**			0.205*	0.206*			
0.285**	0.510***						
		0.252**				0.280**	0.200***
	0.508***	0.292**					
		0.217*					
			-0.191***				
				0.999***		0.230*	
						0.234**	
						0.263**	
							0.200***

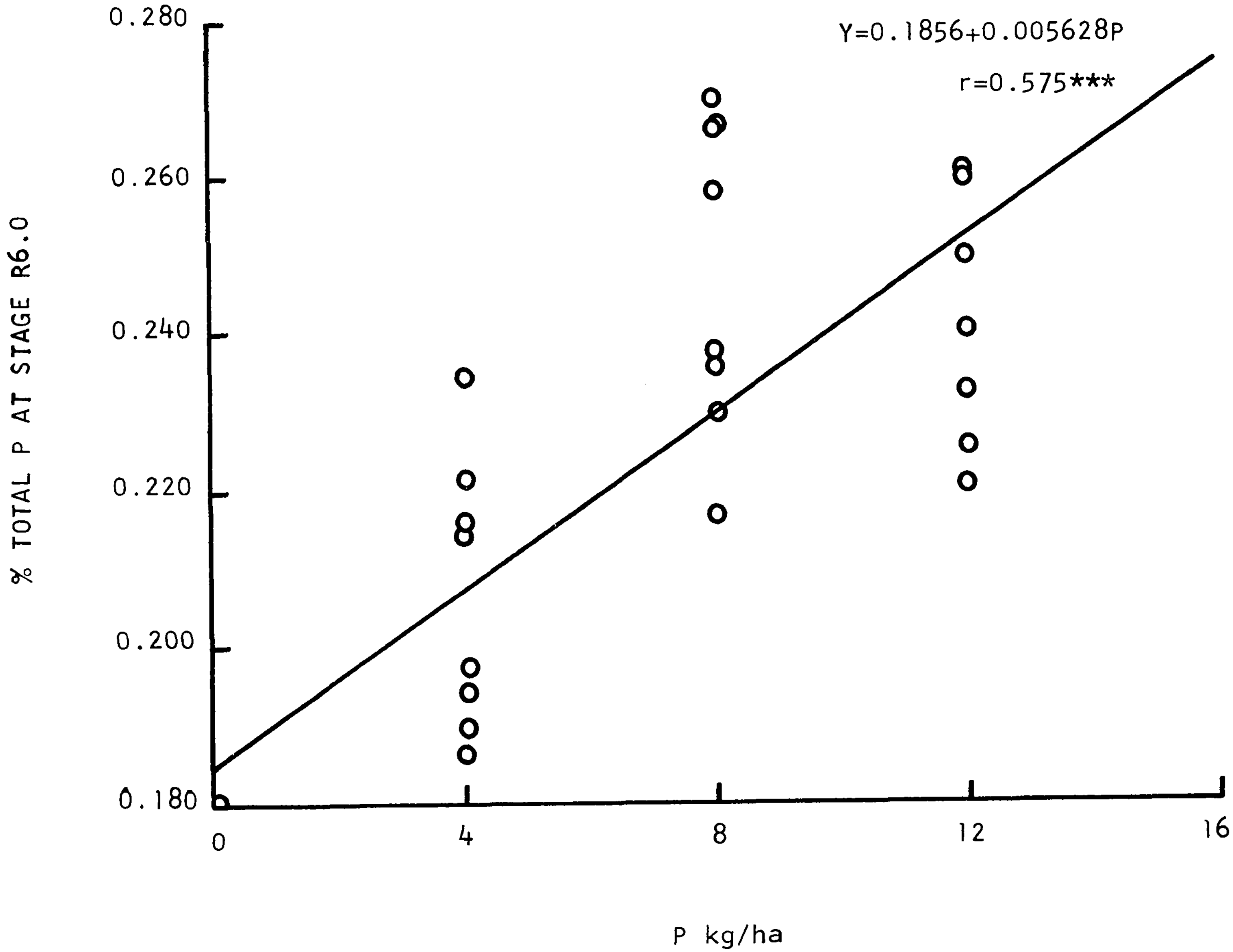
probably due to the fact that at higher doses of N there was not a very significant increase in yield, so the linear model did not fit the data. When a quadratic model was fitted the coefficient of determination obtained was r=0.370**.

The amount of P added as fertilizer was significantly correlated with yield (r=0.270**), the concentration of P in the leaves at stage R6 (r=0.575**, Figure 21) and R6.5 (r= 0.395**) (Table 26). The content of P in the leaves at stage R6 correlated with yields (r=0.390**). These relationships show that the P fertilizer added as foliar spray was able to increase the P content of the leaves and that this P content at stage R6 was a good indication of the response of soybean grain to foliar fertilization.

The amount of K added as fertilizer was significantly correlated with yields (r=0.271***). This relationship was much better expressed when a quadratic model was fitted (Figure 17). There was no significant correlation between the amount of K added as foliar fertilizer and the K content of the leaves and seeds at any stage of development. There is no reasonable explanation for this apart from the fact that, as pointed out by Chamel (1971) working with corn, K is rapidly translocated from the leaves as soon as it is absorbed.

Table 26 shows that at each stage of development there were positive and significant correlations among the N, P and K contents of the leaves. Also it can be observed that there is a correlation between the nutrient contents of the leaves at

Figure 21. Relationship between P added as foliar spray and the P content of the leaves at stage R6, factorial experiment 1975


Y=0.1856+0.005628P
r=0.575***
% TOTAL P AT STAGE R6.0
0.280
0.260
0.240
0.220
0.200
0.180
0
4
8
12
16
P kg/ha

different stages of development for each nutrient.

The N content in the beans was correlated with the N content in the leaves at stage R6 (r=0.205*). This stage of development could be considered as a good indication of the N and protein content of the beans. The K content in the leaves at stages R5.5 and R6 also correlated with the K content of the beans (r=0.350** and 0.280**, respectively). The concentration of N and P in the beans are correlated with the K content of the beans. The variable "weight of 100 seeds", which expresses the size of the seeds, is positively correlated with yield, and the K content of the leaves at stage R6 and in the beans (r=0.248**, 0.200*** and 0.200***, respectively).

a. Water soluble carbohydrates (WSC) content of leaves and beans The percentage of soluble carbohydrates at 3 stages of development in leaves and beans at harvest were determined for 11 of the 26 treatments. The results appear in Table 27. There was a significant effect due to treatments in the leaves at stages R5.5 and R6. This effect was not significant at stage R6.5 and for the seed content of carbohydrates at harvest. The WSC tends to increase for all the treatments between stages R5.5 and R6. The only exception to this was treatment 20 in which the carbohydrate content was maintained fairly high at both stages of development (16.02% at stage R5.5 and 16.56% at stage R6).

The WSC content of the leaves decreased steadily for all the treatments after stage R6. At stage R5.5 the average

Table 27. Water soluble carbohydrate contents of leaves at stages R5.5, R6 and R6.5 and seeds at harvest in 11 treatments, factorial experiment 1975

					% soluble carbohydrate[a]			
					Leaves			
					Stage of development			Seeds
Trt. no.	N	P	K	S	R5.5	R6	R6.5	at harvest
26	0	0	0	0	11.5 c	16.2 bc	13.7	11.9
21	0	8	24	4	11.6 c	17.4 ab	14.9	12.1
22	80	0	24	4	12.7 c	15.6 c	13.8	12.3
23	80	8	0	4	13.9 b	18.1 a	13.3	13.0
24	80	8	24	0	12.1 c	16.2 bc	13.9	13.0
12	40	12	12	2	11.9 c	13.3 d	13.2	13.3
25	80	8	24	4	13.1 bc	16.2 bc	13.6	13.4
20	80	8	24	8	16.0 a	16.6 bc	13.6	12.6
18	80	16	24	4	12.1 c	15.8 c	13.7	13.3
5	120	4	36	6	12.5 bc	12.8 d	12.9	13.4
17	160	8	24	4	11.7 c	18.6 c	14.1	12.9

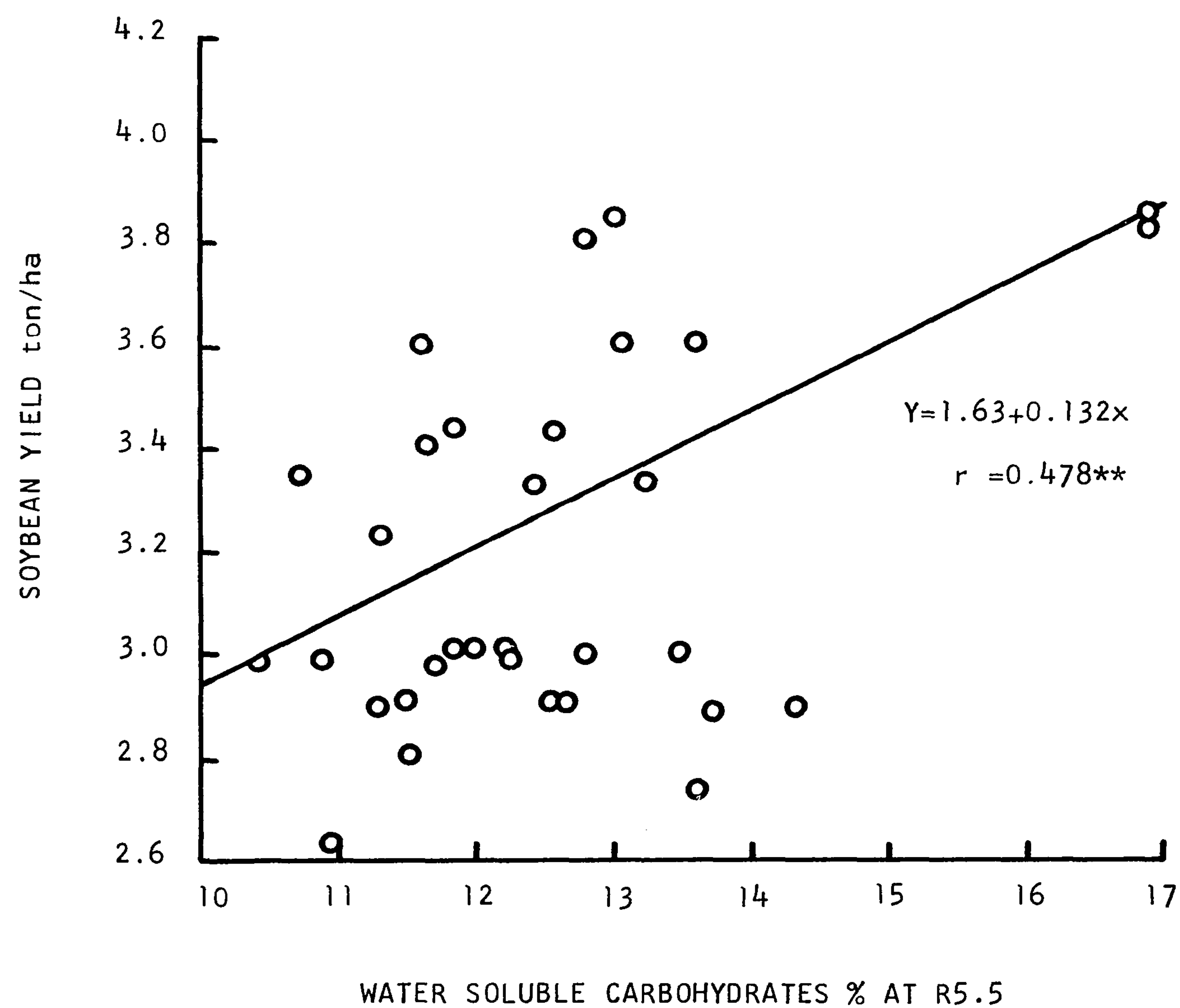
[a]Values within a column followed by the same letter do not differ significantly at 5% level.

content for all treatments is 13.65% compared to 15.80% for stage R6. The average content of carbohydrates in the seed was 12.85%.

The values obtained were in general comparable to those obtained by Dunphy (1972) working with different varieties at different stages of development. At stages R5.5 and R6, the

WSC for treatments 20, 23, and 25 were significantly higher than the values reported by Dunphy (1972). These higher values are a consequence of the significant effect on the WSC of the foliar fertilization. There is a positive significant correlation (r=0.480*) between the WSC at stage R5.5 with yields (Figure 22). This would indicate that the effect of the foliar fertilization, which had an effect in increasing yields, had also an effect on the WSC of the leaves. The three variables are associated, but there is not enough information available to try to explain these results. It is a fact that the WSC was significantly lower in all the treatment combinations in which N, P, K or S, or all of them were 0 (Table 27). Treatments with the highest rates of N and P (160 and 16 kg/ha respectively) also had the lowest WSC. Treatment 20 (80-8-24-8 kg/ha of N, P, K and S, respectively) had the highest value of WSC (16.02%) and there was a significant correlation between the amount of S applied as a foliar spray and the WSC at this stage of development (r=0.589**). WSC at this stage of development was correlated with the N content of the seeds (r=0.356*). Yields were not correlated with WSC at stage R6 but there were significant correlations with amount of P in the leaves at stages R5.5 and R6.5 as well as with the N content of the seeds (r=0.373*, 0.390* and -0.382*, respectively). At this stage of development the WSC do not follow a clear pattern when compared to the foliar treatments, in spite of the significant effect of the latter.

Figure 22, Relationship between water soluble carbohydrates in the leaves at stage R5.5 and soybean yield, factorial experiment 1975



SOYBEAN YIELD ton/ha
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
10
11
12
13
14
15
16
17
WATER SOLUBLE CARBOHYDRATES % AT R5.5
Y=1.63+0.132x
r =0.478**

At stage R6.5 all the values decreased and there were no significant effects between treatments. Nevertheless, there was a significant negative correlation between the WSC at this stage and the N content of the leaves (r=-0.538**).

The WSC in the seeds was correlated with the amount of P added as a foliar spray (r=0.236***), the K content in the leaves at stage R5.5 (r=0.356*), and the concentration of K in the seeds (r=-0.401**). Table 28 shows the most significant correlations obtained when WSC contents were correlated to other variables.

3. Seed size

Table 29 shows the weight of 100 seeds for each treatment combination as well as the yields in ton/ha.

There was a significant effect due to treatments. The highest value obtained was 16.7 g for treatment 24 (8-8-24-0 kg/ha of N, P, K and S) and the lowest value obtained was 15.1 g for treatment 15 (40-4-12-6 kg/ha of N, P, K, S). Treatment 24 had an increase in yield of 320 kg over the check; treatment 15 had a decrease of 120 kg when compared to the check.

All the treatments for which the weight/100 seeds was significantly lower than treatment 24 did not show an important increase in yield. The treatments that showed the highest increase in yield (20, 18, 25 and 4) showed a weight/100 seeds not significantly different from treatment 15. Other evidence

Table 28. Correlation coefficients between WSC and some variables, factorial experiment 1975

		Fertilization		Leaves			Seeds	
				Stage R5.5		Stage 6.5		
WSC %	Yield ton/ha	P kg/ha	S kg/ha	P %	K %	P %	N	P
Stage R5.5	0.478**		0.589**				0.356*	
Stage R6				0.373*		0.390**	-0.382*	
Stage R6.5							-0.538	
Seeds		0.236***			0.346*			-0.401**

***Significant at 10% level.

*Significant at 5% level.

**Significant at 1% level.

Table 29. Effect on weight of 100 seeds of foliar fertilization applied between plant developmental stages R5 and R7, factorial experiment 1975

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Yield ton/ha	Weight/100 seeds (g)[a]
26	0	0	0	0	2.980	15.8 abcd
21	0	8	24	4	2.809	15.7 bcd
22	80	0	24	4	3.092	15.9 abcd
23	80	8	0	4	2.838	15.7 bcd
24	80	8	24	0	3.292	16.7 a
16	40	4	12	2	2.999	16.3 ab
15	40	4	12	6	2.863	15.1 d
14	40	4	36	2	3.398	15.2 cd
13	40	4	36	6	3.352	16.0 abcd
12	40	12	12	2	3.250	15.7 ab
11	40	12	12	6	2.934	15.8 abcd
10	40	12	36	2	2.955	15.5 bcd
9	40	12	36	6	3.021	16.1 abc
25	80	8	24	4	3.549	16.2 ab
20	80	8	24	8	4.024	16.3 ab
19	80	8	48	4	3.085	15.7 bcd
18	80	16	24	4	3.621	16.3 ab
8	120	4	12	2	2.967	15.8 abcd
7	120	4	12	6	3.021	15.9 abcd
6	120	4	36	2	2.858	15.9 abcd
5	120	4	36	6	2.948	15.1 d
4	120	12	12	2	3.343	15.4 bcd
3	120	12	12	6	3.310	16.0 abcd
2	120	12	36	2	3.144	15.6 bcd
1	120	12	36	6	3.224	15.9 abcd
17	160	8	24	4	2.960	15.7 abcd

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

that corroborates this is the fact that there was a significant correlation between yields and weight/100 seeds (r= 0.248**). The weight/100 seeds also correlated with the K content at stage R6 and in the seeds (r=0.200*** and 0.201***, respectively.

Assuredly the foliar fertilization had an effect on the weight/100 seeds; this effect does not appear to be very extraordinary when the 26 different treatments are observed due to the great number of variables and interactions involved. It could be postulated that separately from the effect of the weight/100 seeds just discussed, yield increases from foliar applications of N, P, K, S solutions during the seed-filling period resulted primarily from an increased number of harvestable seeds, rather than seed size. This would indicate that many seeds are normally initiated but are never filled and later are aborted. This implies that the potential yield increase obtainable from a foliar fertilizer application will be influenced by the number of seeds that are initiated but that normally would not be filled.

4. Yield components

In 10 of the 26 treatments the whole plants were harvested separately and divided into 3 parts (the top, middle and the bottom). The seeds of these 3 parts were weighed separately.

To evaluate the effect of the different treatments on each of the 3 parts, analyses of variance were calculated separately for the top, the middle and the bottom segments. This in turn could indicate which part of the plant was responsible for the yield increase. Table 30 shows the values for the 10 treatments.

The effect due to treatments was highly significant (prob of F = 0.001) for the top part of the plants. The middle and bottom segments show little significance (prob of F = 0.15 and 0.12 respectively). These results would indicate that the increases in yield occurred mainly on the top part of the plants. When the weights of this part of the plant are correlated with the yields obtained for the 10 treatments, the correlation coefficient is 0.741**. There were no significant correlations between yields and the weights of seeds from the middle and bottom parts of the plants. Considering the results of the weight of 100 seeds and the fact that the top parts of the plants were responsible for the increases in yield obtained, it can be postulated that when the plants are fertilized with a foliar spray of N, P, K and S the seeds in the upper pods are more completely filled with larger beans.

At stage R6.2 the proportion of green leaves in each treatment was measured and recorded as a percentage of green leaves per treatment. At this stage of development normally the leaves are turning yellow and falling. There was a significant effect due to treatment on the percentage of green leaves at stage R6.2. The average values ranged from 23% for

Table 30. Dry weight of seeds from the top, middle and bottom of plants from different treatments (average of 3 replications), factorial experiment 1975

Trt. no.	Nutrients applied (kg/ha)				Weight of seeds (g)[a]			
					Position on the plant			
	N	P	K	S	Top	Middle	Bottom	Total
1	120	12	36	6	81.3 b	111.3	70.3	262.2
2	120	12	36	2	88.0 b	103.0	73.0	264.0
5	120	4	36	6	77.3 b	108.6	93.3	279.3
9	40	12	36	6	98.0 ab	141.0	70.3	309.3
16	40	4	12	2	113.6 ab	130.6	90.0	334.4
18	80	16	24	4	124.6 a	123.0	87.0	334.7
20	80	8	24	8	133.0 a	121.3	93.6	348.0
22	80	0	24	4	107.0 ab	107.6	68.3	283.0
24	80	8	24	0	100.3 ab	120.3	75.6	296.3
26	0	0	0	0	92.6 b	120.6	79.3	292.7

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

treatment 26 (check) to 81% for treatment 17 (160-8-24-4 kg/ha of N, P, K and S). The results appear in Table 31.

Spraying N, P, K, and S as a fertilizer showed a physiological response of the plant, which resulted in a greener coloration of the leaves and a delay in senescence. In spite of the fact that the data in Table 31 are only from visual observations and were recorded only as a percentage, the big

Table 31. Effect of the foliar fertilization on the proportion of green leaves (%) at stage R6.2, factorial experiment 1975

Trt. no.	Total nutrient application (kg/ha) N	P	K	S	Green leaves at stage R6.2, %[a]
26	0	0	0	0	23 e
21	0	8	24	4	37 de
22	80	0	24	4	65 abc
23	80	8	0	4	50 bcd
24	80	8	24	0	67 abc
16	40	4	12	2	57 abcd
15	40	4	12	6	65 abc
14	40	4	36	2	53 bcd
13	40	4	36	6	40 cde
12	40	12	12	2	52 bcd
11	40	12	12	6	43 cde
10	40	12	36	2	40 cde
9	40	12	36	6	42 cde
25	80	8	24	4	60 abcd
20	80	8	24	8	77 a
19	80	8	48	4	55 bcd
18	80	16	24	4	60 abcd
8	120	4	12	2	58 abcd
7	120	4	12	6	63 abcd
6	120	4	36	2	50 bcd
5	120	4	36	6	43 cde
4	120	12	12	2	73 ab
3	120	12	12	6	57 abcd
2	120	12	36	2	62 abcd
1	120	12	36	6	50 bcd
17	160	8	24	4	82 a

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

differences between treatments observed are a clear indication that the foliar spray had an effect on this variable.

The percentage of green leaves at stage R6.2 correlated significantly with yield (r=0.283**) and the amount of N added as foliar spray (r=0.463***). This might indicate that N had an important role to play in retarding the senescence of the leaves and in increasing yields. The concentrations of N and P in the leaves at stages R5.5, R6 and R6.5 were also correlated with the percentage of green leaves at stage R6.2. The correlation coefficients between % N in the leaves and percentage of green leaves at stage R6.2 were 0.367**, 0.350** and 0.448*** for stages R5.5, R6, and R6.5, respectively. It is worth pointing out that the highest correlation coefficient corresponds to stage R6.5 which is close to physiological maturity. The correlation coefficients between % P in the leaves and percentage of green leaves at stage R6.2 were 0.314**, 0.424** and 0.214* for stages R5.5, R6, and R6.5, respectively.

V. RESPONSE TO FOLIAR FERTILIZATION APPLIED AT DIFFERENT STAGES OF DEVELOPMENT

A. Materials and Methods

These experiments were conducted in 3 locations to study the effects of different times of foliar application: at the Agronomy Research Center near Ames, at the Clarion-Webster Experimental Farm near Kanawha and at the Galva-Primghar Experimental Farm near Sutherland. Some characteristics concerning these experiments as soil type, soil fertilization, soil fertility, cultivars, row spacing and rainfall are shown in Table 32.

The experimental plan was to apply a total of 120-12-36-6 kg/ha of N-P-K-S for each of the 5 different time-of-application treatments. Table 33 shows the different time-of-application treatments as well as the number of times that each one was sprayed and the total amount of N-P-K-S applied for Ames, and Kanawha.

It was not possible to apply the total of 120-12-36-6 planned for all the treatments. In the case of treatment A-5 it was going to be sprayed 14 times, but only 13 could be applied. The reason for this was that after the 13th application, physiological maturity was reached. Similar conditions occurred for treatment K-3.

In treatments A-1 and K-1 , it was not possible to apply more than 24 kg/ha of N in each application due to possible

Table 32. Some characteristics of the different experiments

Location	Soil type	Fertilization $N - P_2O_5 - K_2O$	Soil analysis: Organic matter	P kg/ha	K kg/ha
Ames	Nicollet sicl	0 - 112 - 110	2.65	87.80	238.36
Kanawha	Webster sicl	0 - 0 - 200	4.02	20.74	222.30
Sutherland	Galva sicl	0 - 100 - 100			

Soil analysis					
S ppm	pH	Variety	Row spacing (cm)	Planting date	Rainfall (cm) May-August
10.00	5.26	Corsoy	76	5/15	32.08
8.00		Hark	102	5/22	32.06
		Corsoy	76	5/22-6/13	44.76
		Steele	76	5/22-6/13	
		Clay	76	5/22-6/13	

Table 33. Times of application and doses used in different locations

Location	Time of application	Trt. no.	No. of applications	Total application N	P	K	S
Ames	R4.5-R7	A-5	13	112	11	33	5.6
Ames	R4.5-R6.9	A-4	6	120	12	36	6
Kanawha	R4.5-R6.9	K-4	6	120	12	36	6
Ames	R5-R6	A-2	4	120	12	36	6
Kanawha	R5-R6	K-2	5	120	12	36	6
Ames	R5-R6.4	A-1	4	96	9.6	29	4.8
Kanawha	R5-R6.5	K-1	4	96	9.6	28.8	4.8
Ames	R6-R6.7	A-3	4	120	12	36	6
Kanawha	R6-R6.5	K-3	2	48	4.8	14.4	2.4

burning. Since the idea was to spray 4 times (2 during R5 and 2 after R6) and there were no more than 7 days between each application, it was not possible to include a 5th spray (in order to complete the total amount of 120-12-36-6) without going beyond the physiological stage already set for those treatments. At the Sutherland experiment sprays were applied at 8-10 day intervals between developmental stages R2 and R7. The number of spraying varied from 4-8. 30-3-9-1 kg of N-P-K-S/ha was applied at each spraying. In this experiment the foliar fertilization was tried on 3 different cultivars of soybeans, each one of them planted at 2 different times.

Table 34 shows the different cultivars used, the total amount of N-P-K-S applied on each cultivar, and the number of times of application.

Table 34. Doses, times of application and cultivars used in the Sutherland experiment

Total foliar application (kg/ha) N - P - K - S	No. of times	Cultivar	Planting date
240 - 24 - 72 - 12	8	Corsoy	May 22
240 - 24 - 72 - 12	8	Steele	May 22
120 - 12 - 36 - 6	4	Clay	May 22
240 - 24 - 72 - 12	8	Corsoy	June 13
210 - 21 - 63 - 10	7	Steele	June 13
180 - 18 - 54 - 9	6	Clay	June 13

A complete randomized block design with 3 replications was used in all the experiments. The size of the plots was 4 rows (0.76 m and 1.01 m row distance for Ames, Sutherland, and Kanawha, respectively) by 4 m (12.16 and 16.16 m^2, respectively).

The fertilizer solutions were prepared and sprayed using the same chemical compounds and procedures described before for the factorial experiment.

Samples of the youngest mature leaf were taken for each treatment before each spray application starting at stage R4 and through stage R7. Plant samples were handled and analyzed for N, P and K in the same way as the 1974 experiment described previously.

The experiment at Ames was harvested on October 6, the Kanawha experiment on October 10 and Sutherland on October 15. Harvesting was done by cutting at ground level the interior 3 meters of the second and third row of each plot and threshing them in a plot thresher.

Soybean samples were taken from each treatment and N, P, K analyses were run. In addition, the weight of 100 seeds was measured.

B. Results and Discussion

1. Yield responses at Ames and Kanawha

The objective of these experiments was to study the effects of different times of foliar application at Ames and Kanawha. The results are reported in Tables 35 and 36.

The experimental plan was to apply a total of 120-12-36-6 kg/ha of N-P-K-S for each of the different time-of-application treatments. For various reasons, this was not accomplished for all the treatments at either site. Therefore, it was not possible to evaluate the effects of all times of application independent of the amounts of nutrients applied.

The maximum yields obtained were 3.505 and 2.834 ton/ha

Table 35. Effect on soybean yields of different times of foliar applications; time of application experiment, Ames, 1975

Trt. no.	Total nutrient application, kg/ha N	P	K	S	Times of application	No. of appli-cations	Yield[a] ton/ha	Yield increase from spraying
1-A	96	9.6	29	4.8	From R5 to R6.4	4	3.505 a	577
2-A	120	12	36	6	From R5 to R6	4	2.460 c	-170
3-A	120	12	36	6	From R6 to R6.7	4	2.688 c	-242
4-A	120	12	36	6	From R4.5 to R6.9	6	2.953 bc	23
5-A	112	11	33	5.6	From R4 to R7	13	3.230 ab	300
6-A	0	0	0	0			2.930[b]	

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

[b]The yield of the check plot was not included in the statistical analysis.

Table 36. Effect on soybean yields of different times of foliar applications; time of application experiment, Kanawha, 1975

Trt. no.	Total nutrient application, kg/ha				Times of application	No. of applications	Yield[a] ton/ha	Yield increase from spraying
	N	P	K	S				
1-K	96	9.6	28.8	4.8	From R5 to R6.5	4	2.936 a	386
2-K	120	12	36	6	From R5 to R6	4	2.517 b	- 33
3-K	48	4.8	12.4	2.4	From R6 to R6.5	2	2.553 b	3
4-K	120	12	36	6	From R4 to R6.5	6	2.628 b	73
6-K	0	0	0	0			2.550[b]	

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

[b]The yield of the check plot was not included in the statistical analysis.

at Ames and Kanawha, respectively. The plots without foliar fertilization yielded 2.930 and 2.550 ton/ha, respectively.

There was a significant effect due to treatments in both experiments. The foliar treatment that consisted of a total of 96-9.6-28.8-4.8 kg/ha of N, P, K and S in four applications between developmental stages R5 and R6.5 resulted in significant increases in soybean yields--577 kg/ha at Ames and 384 kg/ha at Kanawha. Applying lesser amounts of nutrients at each spraying and increasing the number of sprayings to 13 between stages R4 and R7 (sprayed every third day) resulted in a smaller yield increase--300 kg/ha--in the Ames experiment. The treatment that consisted of 120-12-36-6 kg/ha of N, P, K and S in six applications between stages R4.5 and R6.9 resulted in no yield increase. The failure of these applications may indicate that applications must be made throughout the period from R5 to R7. However, since in the factorial experiment discussed previously, the yield increase from foliar treatments that included 120 kg N/ha were small in comparison to those that included 80 kg N/ha, the failure of these treatments to increase yields may be due to the higher rate of nutrient application used in these treatments rather than the time of application.

Other reasons that would explain why there was not an increase in yield in some of the treatments is that the foliar spray was applied either too early or too late. In the first situation (treatments 4-A, 4-K, 2-A and 2-K) a considerable amount of the fertilizer was applied during stages R4 and R5. At these stages of development, the seeds are starting to form in the upper pods and for several reasons some of them abort. This means that the pods that are left and which would benefit from the foliar fertilization would not have a later chance to get the amount of nutrients needed to increase yield. In addition to this, treatments 2-A - K and 4-A - K showed severe leaf burning after the first application and this probably had a negative effect on yields.

The opposite situation probably occurred with treatment 3, which received the foliar fertilization after stage R6. After stage R6 the pods are already filled with seeds which had also reached a maximum development. Under these circumstances it is very unlikely that the foliar fertilization would have had any effect. In addition to this, when the last spray was applied (stage R6.9) 40% of the leaves were turning yellow. Additional studies on different times of application of foliar sprays are needed in order to clarify these results.

2. <u>Sutherland experiment</u>

Because of a misunderstanding, foliar applications at the Sutherland experiment were begun at plant developmental stage R2 instead of R5. The results are reported in Table 37. The foliar sprays were then made every 8 to 10 days until almost stage 7. 30-3-9-1 kg/ha of N, P, K and S were applied at each spraying. This resulted in very large total nutrient applica-

Table 37. Effect on soybean yields of different times of foliar applications on different varieties and planting time, Sutherland experiment, 1975

Total foliar application, kg/ha				No. of times	Variety	Planting date	Yield not sprayed	Yield sprayed	Yield increase
N	P	K	S						
240	24	72	12	8	Corsoy	May 22	3.594	3.203	-391
240	24	72	12	8	Steele	May 22	3.112	3.112	0
120	12	36	6	4	Clay	May 22	1.680	2.122	442
240	24	72	2	8	Corsoy	June 13	2.969	2.891	-78
210	21	63	10	7	Steele	June 13	2.969	2.930	-39
180	18	54	9	6	Clay	June 13	2.118	1.836	-281

tions for the season with the exception of Clay cultivar planted on May 22.

There was not a significant effect due to the foliar fertilization in this experiment, but it could be observed that similar to the factorial experiment (Table 15), the very high rates of nutrient application resulted in no yield increases and resulted in small yield decreases for two of the treatments. Only one treatment, with the smallest rate of application in the experiment (120-12-36-6 kg/ha of N, P, K and S), resulted in a small but not significant increase in yield (442 kg/ha).

3. Chemical analysis of leaves and grain

Tables 38 and 39 show the N, P and K content of the leaves and grain at different stages of development (R5, R5.5, R6 and R6.5) for each treatment in Ames and Kanawha. In order to detect possible effects due to treatments, analyses of variance were calculated for each nutrient content of the leaves and grain at the 4 stages of development.

The treatment means are significantly different at each stage of development for both locations.

The N, P and K content of the leaves decrease with time, but the values are higher than the check at each stage of development.

In both experiments, treatment 1 shows the higher values for N and P at stages R6 and R6.5. The K content for this

Table 38. N, P, K and protein content in the leaves and grain at different stages of development, time of application experiment, Ames 1975

Trt. no.	Nutrient content of leaves[a]							
	% N				% P			
	Stage of development				Stage of development			
	R5	R5.5	R6	R6.5	R5	R5.5	R6	R6.5
1-A	3.78 b	3.69 ab	3.42 a	2.79 a	.424 a	.317 b	.318 ab	.301 a
2-A	3.84 b	3.87 a	3.40 a	1.89 b	.250 c	.376 a	.377 a	.169 b
3-A	3.74 b	2.88 d	2.93 b	2.64 a	.241 c	.201 d	.199 b	.299 a
4-A	3.94 ab	3.48 bc	2.80 b	2.57 a	.331 b	.334 ab	.266 ab	.314 a
5-A	4.11 a	3.44 c	3.55 a	2.43 a	.284 b	.267 c	.301 ab	.296 a
6-A	3.74 b	2.88 d	2.78 b	1.91 b	.246 c	.201 d	.200 b	.160 b

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

Table 39. N, P, K and protein content in the leaves and grain at different stages of development, time of application experiment, Kanawha 1975

Trt.	Nutrient content of leaves[a]							
	% N				% P			
	Stage of development				Stage of development			
	R5	R5.5	R6	R6.5	R5	R5.5	R6	R6.5
1-K	4.70 a	3.67 bc	3.98 b	3.31 a	.337 b	.298 b	.459 a	.426 a
2-K	4.59 a	4.30 a	4.29 a	2.52 bc	.362 a	.483 a	.470 a	.186 c
3-K	4.12 b	3.38 c	2.70 c	2.79 b	.314 c	.258 b	.235 b	.304 b
4-K	4.41 ab	4.02 ab	3.78 b	3.37 a	.339 b	.438 a	.490 a	.387 a
6-K	4.16 b	3.38 c	2.70 c	2.08 c	.313 c	.285 b	.235 b	.161 c

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

Nutrient content of leaves: % K, Stage of development R5	R5.5	R6	R6.5	Nutrient content of beans: N %	P %	K %	% protein	Yield ton/ha
1.28 b	1.20 bc	1.20 b	0.98 b	6.44	.548	1.91	40.29	3.505 a
1.28 b	1.36 ab	1.43 a	0.79 c	6.16	.538	1.98	34.54	2.460 c
1.27 b	1.06 c	0.86 d	0.95 b	6.35	.535	1.97	39.73	2.688 c
1.51 a	1.48 a	1.04 c	1.20 a	6.35	.526	1.94	39.69	2.953 bc
1.33 b	1.18 c	1.23 b	0.93 b	6.43	.516	1.92	40.43	3.230 ab
1.27 b	1.06 c	1.18 b	0.78 c	6.08	.544	1.93	37.62	2.930

Nutrient content of leaves: % K, Stage of development R5	R5.5	R6	R6.5	Nutrient content of beans: N %	P %	K %	% protein	Yield ton/ha
1.02 b	0.78 b	1.13 a	0.89 b	7.26 b	.582 b	1.86 d	48.41 b	2.936 a
1.17 a	1.02 ab	1.20 a	0.62 c	7.79 a	.586 b	1.89 c	48.73 a	2.518 b
1.02 b	0.84 b	0.66 b	0.89 b	7.45 ab	.599 b	1.92 b	46.58 ab	2.555 b
1.14 a	1.17 a	1.05 a	1.23 a	7.46 ab	.621 a	1.98 a	46.64 ab	2.628 b
1.05 b	0.84 b	0.66 b	0.45 c	7.03 b	.601 b	1.89 c	43.93 b	2.552

treatment was higher than the check at these stages of development. These values are related with the foliar fertilization which took place for this treatment between stages R5 and R6.4.

Treatments 2-A and 2-K showed higher values for N, P and K at stages R5.5 and R6; this agrees with the time that this treatment received foliar fertilization (from stage R5 to R6). Treatment 3 showed higher values for N, P and K at stage R6.5 in the experiment at Ames. This was predictable since it was treated from stages R6 to R6.7. This relationship does not show up in the experiment at Kanawha.

The general trend for treatment 4 shows higher values for N, P and K throughout all the period which was fertilized (from stage R4.5 to R6.9).

In spite of the fact that treatment 5 consisted of foliar fertilization every 3 days from stages R4 to R7, the N, P and K contents of the leaves do not show significantly higher values than the other treatments at any stage of development. However, the nutrient content was higher than the check and comparable to other treatments at different stages of development. Figures 23 and 24 compare the variations of N and P content in the leaves with time between treatment 1-A and the check. It can be observed that in both figures the concentration of N and P in treatment 1-A is much higher than the check.

There were no significant differences due to treatments

Figure 23. Variation of N content in the leaves with time after sprayed with an N, P, K, S solution between stages R5 and R6.4; time of application experiment, Ames, 1975

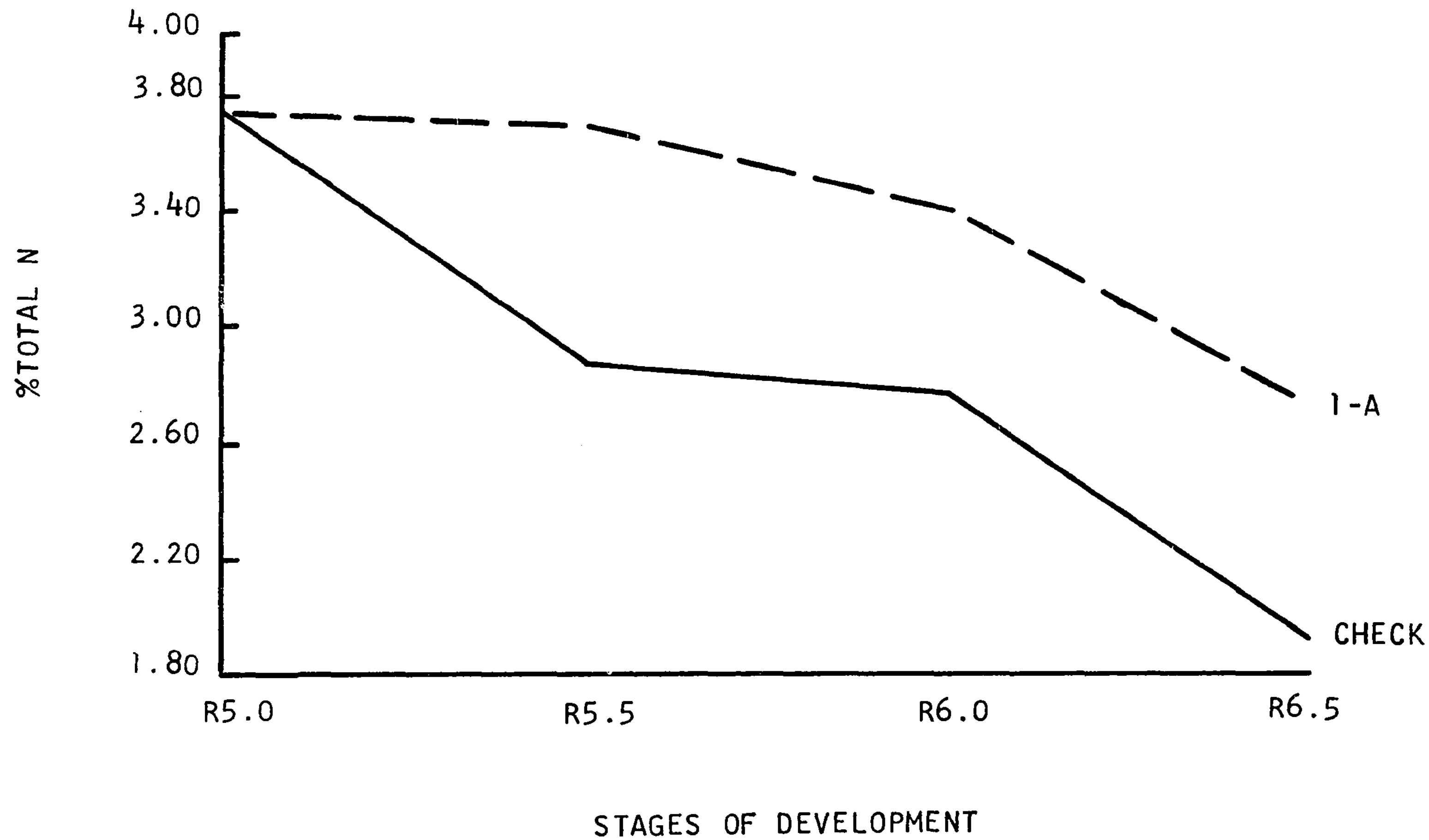
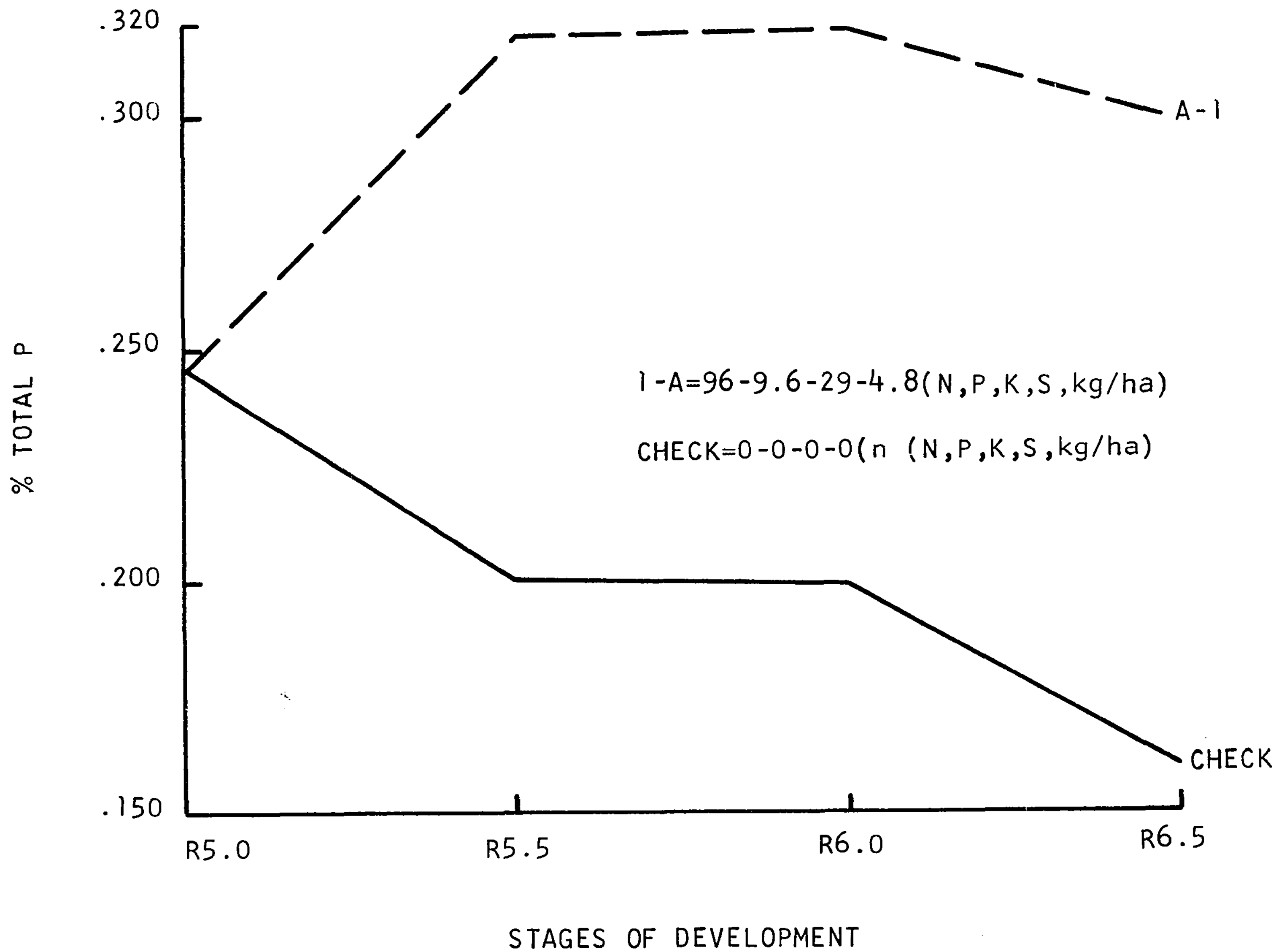

4.00
3.80
3.40
3.00
2.60
2.20
1.80
%TOTAL N
1-A
CHECK
R5.0
R5.5
R6.0
R6.5
STAGES OF DEVELOPMENT

Figure 24. Variation of P content in the leaves with time after sprayed with an N, P, K, S solution between stages R5 and R6.4; time of application experiment, Ames, 1975


.320
.300
.250
.200
.150
% TOTAL P
A-1
CHECK
1-A=96-9.6-29-4.8(N,P,K,S,kg/ha)
CHECK=0-0-0-0(n (N,P,K,S,kg/ha)
R5.0
R5.5
R6.0
R6.5
STAGES OF DEVELOPMENT

for the N, P, and K content of the seeds at the Ames experiment. The average content for N, P and K were 6.30, 0.534 and 1.94%, respectively.

These differences are significant at the Kanawha experiment. The highest values for N were obtained with treatments 2-K, 3-K and 4-K. Treatments 1-K and the check had the lowest values (7.26 and 7.03% of N). Treatment 4-K had the highest values for P and K content in the seeds (0.621 and 1.98%). The lowest contents were in seeds from the check and treatment 1-K.

It can be established that the treatments which did not have an increase in yield showed the highest values for N, P and K in the seeds. Probably because these applications were done too early or too late, the nutrients were just translocated into the seeds and did not have the possibility to fully develop the seeds. There is no experimental evidence to support this hypothesis.

Tables 40 and 41 show the most significant correlation coefficients computed between the analytical values of the leaves and beans at different stages of development and yields at Ames and Kanawha.

At both locations yields correlated with the N content of the leaves at stages R6 and R6.5 (Tables 40 and 41). The same kind of results were obtained in the factorial experiment discussed in the previous section, where yields correlated with the nitrogen content of the leaves at stage R6. These correlations can also be explained by the fact that treatment 1--

Table 40. Coefficients of correlation between variables, times of application experiment, Ames 1975

	Leaves						
	Stages of development						
	R5			R5.5			
	N %	P %	K %	N %	P %	K %	N %
Yield							.426*
N % R5		.572**					
P % R5			.713**			.550**	
K % R5						.470*	
N % R5.5					.928**	.709**	.547**
P % R5.5						.783**	.421*
K % R5.5							
N % R6							
P % R6							
K % R6							
N % R6.5							
P % R6.5							
K % R6.5							

*Significant at 5% level.

**Significant at 1% level.

Leaves							
Stages of development							
R6		R6.5			Seeds		
P %	K %	N %	P %	K %	N %	P %	K %
		.439*					-.551
						-.457*	
				.695**			
				.563**			
.826**	.603**						
.826**	.571**						
.454*							
.766**	.612**						
	.766**						
		.536**	-.537**	-.459*			
			.842**	.617**	.454*		
				.786**			

Table 41. Coefficients of correlation between variables, times of application experiment, Kanawha 1975

	Leaves						
	Stages of development						
	R5			R5.5			
	N %	P %	K %	N %	P %	K %	N %
Yield							.438*
N % R5		.703**		.463*	.508*		.800**
P % R5			.547*	.800**	.837**		.867**
K % R5				.620*	.682**	.636**	.447*
N % R5.5					.802**	.453*	.755**
P % R5.5						.541*	.746**
K % R5.5							
N % R6							
P % R6							
K % R6							
N % R6.5							
P % R6.5							
K % R6.5							
P seeds							

*Significant at 5% level.

**Significant at 1% level.

Leaves							
Stages of development							
R6		R6.5			Seeds		
P %	K %	N %	P %	K %	N %	P %	K %
		.422*	.560**				
.706**	.800**	.445*					
.729**	.707**				.500*		
					.533**		
.747**	.513*				.576*		
.741**	.640**				.651**		
				.489*			.571*
.893**	.909**	.465*			.535*		
	.813**	.542**					
		.523*					
			.883**	.832**			
				.790**			
							.599**
							.793**

which was the one that produced significant yield increases--showed higher values for N in the leaves at these stages of development. As discussed before these higher values could be expected assuming that this treatment received applications of foliar fertilizer at stages R5.5 through R6.5.

All the other significant correlations which appear in Tables 40 and 41 generally corroborate what was found in the factorial experiment previously discussed.

VI. RESPONSE OF DIFFERENT CULTIVARS OF SOYBEANS TO FOLIAR FERTILIZATION

A. Materials and Methods

The experiment was conducted to study the effects of foliar applications on 3 soybean cultivars grown under reasonably optimum conditions.

The experiment was planted on May 15 at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames (Bruner) on soil in a soybean-corn crop sequence. The soils in the experimental area were classified as Webster (Typic Haplaquoll) and were high in P (Bray dilute-acid P test = 67 kg/ha) and were medium in K (moist exch K = 151 kg/ha).

The cultivars used were Corsoy, Amsoy, and Hark, which were grown in narrow, 35-cm rows. A split-plot randomized block design with two replicates was used. Each cultivar was divided into two sub-plots (both of which comprised the main plot). One sub-plot received a total foliar fertilization of 96-9.6-22.2-4.8 kg/ha of N, P, K, and S; the other was the check. The fertilizer was applied in 4 foliar applications between plant developmental stages R5 and R7. Each main plot was 10 rows (3.5 m) by 8 m and the sub-plots were 10 rows (3.5 m) by 4 m.

The experiment was harvested on October 10 by following the same procedure as the factorial experiment described as before. Leaf samples were taken at developmental stage R5.5, R6, and R6.5, and chemical analyses were run on these for N, P, and K. To avoid severe moisture stress the plots were irrigated twice during the unusually dry summer period.

B. Results and Discussion

Table 42 shows the yields obtained for the different cultivars and the effects of the foliar fertilization. There was a significant effect due to cultivar difference as well as the effects of foliar treatment and the interaction of them.

Table 42. Effect of foliar fertilizer application between plant developmental stages R5 and R7 on yields of 3 soybean cultivars[a], variety experiment 1975

Soybean cultivar	Yield sprayed (ton/ha)	Yield not sprayed (ton/ha)	Yield increase from spraying (kg/ha)
Corsoy	5.113 a	3.540 a	1570
Hark	3.728 b	4.565	-837
Amsoy	5.340 a	3.850 a	1490

[a]Values within a column not followed by the same letter differ significantly at the 5% level.

The yields of the nonsprayed plots varied from 3.5 tons/ha for Corsoy to 4.5 tons/ha for Hark. These untreated plots are exceptionally high probably due to narrower row spacing, irrigation, and the fertility of the soil. When treated, there was a significant increase in yield. The maximum yield obtained was 5.34 tons/ha for Amsoy. Corsoy yielded 5.13 tons/ha. These increases represented 1570 and 1490 kg/ha for Corsoy and Amsoy, respectively. These are the largest yield increases obtained in comparison to all other experiments reported. The reason being most likely due to the fact that the closer the yield potential is achieved the greater are the probabilities of obtaining a yield increase due to foliar fertilization.

The Hark cultivar responded negatively to the foliar fertilization (Table 42). There is not enough experimental data to explain this negative response. Studying the data it seems that there is the possibility that during the harvesting mislabeling of the sprayed and nonsprayed samples occurred which led to the obtained results. Table 43 shows the effect of the foliar fertilization on the nutrient content of the leaves at 3 stages of development. The values reported are averages for the three cultivars studied.

The N, P and K contents in the leaves were consistently higher through all the stages of development. These results agree with what was reported before in this thesis concerning the effect of the foliar fertilization on the nutrient content of the leaves.

Table 43. N, P and K content in the leaves and grain at different stages of development, average of 3 cultivars, variety experiment 1975

	Stage of development											
	R5			R5.5			R6			Seeds		
Treatment	N	P	K	N	P	K	N	P	K	N	P	K
Sprayed	5.17	.350	1.30	4.55	.342	.93	3.57	.301	.91	6.39	.657	1.94
Not sprayed	4.40	.310	1.10	4.05	.276	.75	3.00	.248	.76	6.29	.657	1.93

VII. SUMMARY AND CONCLUSIONS

The results reported here from the two years of field experimentation demonstrate conclusively that soybean yields can be significantly increased by foliar application of an NPKS solution during the seed-filling period. The experimental data indicate that for such foliar applications to be most effective they must supply all four elements, N, P, K, and S, and that the ratio of these nutrients in the foliar spray for soybeans should be approximately 10:1:3:.5. In an experiment conducted in 1974 a maximum increase in yield of 540 kg/ha was obtained after the plants were sprayed late in the growing season with a solution that contained 49-21.4-36-9-150 kg/ha of N, P, K, S, and sucrose, respectively. In 1975, a factorial experiment was conducted in which different rates of N, P, K, and S were applied as a foliar spray. There was a positive response in yield to N, P, K, and S, but the highest yield increase (1.040 ton/ha above a check of 2.980 ton/ha) was obtained when the 4 nutrients were applied together at a ratio of 10:1:3:0.5 or 80-8-24-4 kg/ha of N, P, K, and S, respectively. The results obtained substantiate the hypothesis that nutrient uptake from the soil is not adequate to supply the needs of the plants and avoid the normally observed depletion of N, P, K, and S from the leaves during the seed-filling period. This appears to occur irrespective of the availability of these nutrients in the soil and probably results from inadequate carbohydrate nutrition of the roots during this period. The results obtained show that foliar sprays with an NPKS solution during this period should minimize this nutrient depletion of the leaves so photosynthesis would be maintained at a higher level resulting in increased yields. Foliar sprays had a significant effect on the N, P, K and carbohydrate content of the leaves and beans. Significant correlations were found between the nutrient and carbohydrate content of the treated leaves and seed yields, as well as the amount of nutrient applied as a foliar spray and the content of that nutrient in the leaves.

The fact that all four nutrient elements are normally depleted in the leaves and that the foliar spray to be most effective must supply all four of the elements in the proportions found in the seeds explains why foliar sprays that supplied only one or two of the elements during the seed-filling period were not very effective in increasing seed yields.

Yield increases from foliar applications of NPKS solutions during the seed-filling period resulted primarily from an increase in number of harvestable seeds, rather than seed size. Also the increases occur mainly in the top part of the treated plants. This indicates that many seeds are normally initiated and are never filled and later are aborted. This implies that the potential yield increase obtainable from a foliar fertilizer application will be influenced by the number of seeds that are initiated but that normally would not be filled.

The results obtained showed that two to four applications during the seed-filling period--between developmental stages R5 and R7--were most effective in increasing seed yields. More frequent applications with lesser amounts at each application were not so effective. Nor were applications only at the beginning or end of the seed-filling period as effective as applications spaced throughout the period. Excessive rates of application (more than 20 kg/ha of N) at any one spraying can result in serious leaf burn and should be avoided.

Foliar applications of NPKS were effective when applied to 3 different varieties of soybeans grown under reasonably optimum conditions. A yield increase of 1.570 ton/ha above a check plot of 3.540 ton/ha was obtained with the Corsoy cultivar, and a yield increase of 1.490 ton/ha above a check plot of 3.850 ton/ha was obtained with the Amsoy cultivar.

VIII. BIBLIOGRAPHY

Ahlgren, G. E. and T. W. Sudia. 1967. Studies of the mechanism of the foliar absorption of phosphate. In Isotopes in plant nutrition and physiology. Proc. Symp. FAO/IAEA, Vienna 1966: 347-369.

Alexander, V. T. 1973. Influence of foliar nutrition of urea and potash on wheat under rain-fed conditions. Potash Review 9/23(12): 1-2.

Aliev, N. A. 1967. Top-dressings increase yields. (In Russian). Sadovodstvo (Mosc.) 1: 24-25. Hort. Abstr. 37(3): 3585.

Ananth, B. R. 1961. A preliminary note on foliar nutrition of coffee. Indian Coffee 25: 235-236.

Anthony, J. L. 1967. Fertilizing soybeans in the hill section of Mississippi. Miss. Agr. Exp. Sta. Bull. 473.

Aronoff, S. 1955. Translocation from soybean leaves. II. Plant Physiol. 30: 184-185.

Asbour, N. I. and S. M. Hegazi. 1972. Response of wheat to foliar nutrition with microelements under Egyptian conditions. Egyptian Journal of Botany 15: 95-102.

Asbour, N. I. and S. A. Saleh. 1973. Effect of foliar nutrition with urea on growth, nitrogen content and yield of wheat plant. Egyptian Journal of Botany 16: 37-41.

Barber, S. A. 1967. Fertilization research on soybeans. Soybean Digest 27(5): 12-13.

Barel, Dirk. 1975. Foliar applications of phosphorus compounds. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Barinov, G. V. 1959. Comparative rates of entry of P^{32} and Ca^{45} and their solubility in plants following foliar application. Doklady Botanical Sciences Sections: A translocation of Dokl. Akad. Nauk SSSR 125(1-6): 88-89.

Barrier, G. E. and W. E. Loomis. 1957. Absorption and translocation of 2,4-dichlorophenoxyacetic acid and P^{32} leaves. Plant Physiol. 32: 225-231.

Beeftink, W. G., J. van der Boon and H. H. Borgman. 1957. Plant nutrition through the leaf. (Du. e.). Meded. Direct. Tuinb. 20: 150-157.

Belikov, I. F. 1955a. Local utilization of products of photosynthesis in soybean (Translated title). Dokl. Adak. Nauk SSSR 102: 379-381. Chem. Abstr. 49: 14916.

Belikov, I. F. 1955b. Movement and distribution of products of photosynthesis in soybean during vegetative period. Fiziol. Rastenii Akad. Nauk SSSR 2: 354-357. Chem. Abstr. 49: 16080.

Belikov, I. F. 1957a. Distribution of products of photosynthesis in soybean after partial removal of the beans and the leaves. Dokl. Akad. Nauk SSSR 117: 904-905. Chem. Abstr. 52: 6506.

Belikov, I. F. 1957b. The distribution of the products of photosynthesis in the soya plant with partial removal of beans and leaves. Dokl. Akad. Nauk SSSR 117: 272-273. Biol. Abstr. 33: 15397.

Belikov, I. F. 1958. The translocation of assimilates in the leaf blade of soya. Dokl. Akad. Nauk SSSR 120: 151-153. Biol. Abstr. 33: 46954.

Belikov, I. F. and R. A. Burtseva. 1966. Effect of foliar spraying with superphosphate on accumulation of fat in soya seeds. (In Russian). Agrokhimiya 4: 45-47.

Belikov, I. F. and R. A. Burtseva. 1967. Effect of extra-root top-dressing with phosphorus on alteration of chemical composition of soybean seeds. (In Russian). Sel'sk. Khoz. Biol. 2: 900-906.

Belikov, I. F. and L. I. Pirskii. 1966. Violation of the local distribution of assimilates in soybeans. Fiziol. Rastenii 13(3): 406-410. Soviet Plant Physiology 13: 361-364.

Belikov, I. F. and I. Thatschenko. 1961. Soybeans in Primorskoja. (In Russian). Sel'khogiz., Vladisvostok.

Bester, A. J. and J. T. Meynhardt. 1968. A study of some factors influencing the foliar uptake of phosphorus by grape vines. S. Afr. J. Agric. Sci. 11: 477-481.

Bezdek, V. and M. Flasarova. 1973. Effect of urea sprays on yields of winter wheat and spring barley. Soils and Fertilizers 37, No. 4.

Bhaskaran, U. P. and R. De. 1971. Foliar spray of urea for yield increase in rice. Curr. Sci. 40: 90-91.

Bhoj, R. L., U. S. Singh and I. P. Singh. 1969. Note on the effect of foliar spray of nitrogen and phosphorus on American cotton, Gossypium hirsutum L. Indian J. Agric. Sci. 39: 178-179.

Biddulph, O. 1960. Radioisotopes in plants: Foliar entry and penetration, p. 73-85. In R. S. Caldecott and L. A. Snyder (eds.) Radioisotopes in the biosphere. Univ. Minn. Gen. Ext. Div., Minneapolis.

Bloomquist, R. V. and C. A. Kust. 1971. Translocation pattern of soybeans as affected by growth substances and maturity. Crop Sci. 11: 390-393.

Boroughs, H. and C. Labarca. 1961. Studies of the mechanism of foliar nutrition in plants. (Sp.e.). Turrialba 11: 160-161.

Boroughs, H. and C. Labarca. 1962. The use of wetting agents in foliar nutrition. Int. J. Appl. Radiat. Isot. 13: 359-364.

Bottini, E. and E. Morra di Lavriano. 1958. Possibilities of plant nutrition through the leaves. Investigations conducted with tomato and chicory. (In Italian). Ann. Sper. Agrar. 12(n.s.): 1175-1190.

Boynton, D. 1954. Nutrition by foliar application. Ann. Rev. Plant Physiol. 4: 31-54.

Bukovac, M. J. and H. Davidson. 1961. Absorption and distribution of sodium, phosphorus, chlorine, calcium, and zinc in some selected woody ornamentals. Biol. Plant. 3: 39-46.

Bukovac, M. J. and S. H. Wittwer. 1957. Absorption and mobility of foliar applied nutrients. Plant Physiol. 32: 428-435.

Bukovac, M. J. and S. H. Wittwer. 1961. Absorption and distribution of foliar applied mineral nutrients as determined with radioisotopes, p. 215-230. In W. Reuther (ed.) Plant analyses and fertilizer problems. American Institute of Biological Science, Washington, D.C.

Burghardt, H. 1961. Blättdungung der Kulturpflanzen. Angew. Bot. 35: 191-214.

Burr, G. O. 1962. The use of radioisotopes by the Hawaiian sugar plantations. Int. J. Appl. Radiat. Isot. 13: 365-374.

Burr, G. O., T. Tanimoto, C. E. Hartt, A. Forbes, G. Sadaoka, F. M. Ashton, J. H. Payne, J. A. Silva and G. E. Sloane. 1956. Uses of Radioisotopes by the Hawaiian Sugar Plantations. Peaceful Uses of Atomic Energy 12: 177-183. United Nations, New York.

Cardoso, A. P., S. Da and H. Boroughs. 1960. Experiments on foliar absorption and translocation of phosphorus-32 by young cacao plants. (Sp.e.). Estud. Agron., Lisboa 1: 197-224.

Carne, R. S. 1966. A fertilizer leaf spray for coffee. Papua New Guinea Agric. J. 18: 80.

Carter, J. L. and T. H. Hopper. 1942. Influence of variety, environment and fertility level on the chemical composition of soybean seed. USDA Tech. Bull. 787.

Caviness, C. C. and G. W. Hardy. 1970. Response of six diverse genetic lines of soybeans to different levels of soil fertility. Agron. J. 62: 236-239.

Chamel, A. 1971. Effects of some factors on the fixation and migration of K^{42} applied to maize leaves. Recent Advances in Plant Nutrition. Proc. 6th Int. Coll. on Plant Ann. & Fert. Problems, Tel Aviv 1970, 2: 395-406.

Chanham, M. C., H. P. Strivastava and C. C. Frederickson. 1971. Aerial application of concentrated urea solution increases yield of rain-fed rice and wheat in India. World Soil Resources Reports No. 41: 228-229.

Chesnin, L. and N. Shafer. 1953. Foliage applications of urea solutions to grain and forage crops. Agron. J. 45: 576.

Chu, C. and Y. L. Ku. 1966. The absorption and translocation of foliar applied P^{32} phosphate and its effect as fertilizer when in combination with C^{14}-urea on rice damaged by salinity. J. Agric. Assoc. China 54: 25-39.

Chumakov, A. E. and M. A. Bystrova. 1958. The effect of foliar spraying winter wheat with mineral supplements in increasing rust resistance. (In Russian). Biol. Abstr. 46(7): 31193.

Colwell, W. E. 1944. Fertilizing soybeans in North Carolina. Better Crops with Plant Food 28(8): 23-25, 44-45.

Cook, J. A. and F. G. Mitchell. 1958. Screening trials of chelated zinc materials toward the correction of zinc deficiency in Vinifera grapevine. Proc. Amer. Soc. Hort. Sci. 72: 149-157.

Crafts, A. S. 1967. Bidirectional movement of labelled tracers in soybean seedlings. Hilgardia 37: 625-638.

Datta, N. P. and K. K. Vyas. 1967. Uptake and utilization of phosphorus by maize from foliar sprays, p. 371-376. In Isotopes in plant nutrition and physiology. Proc. Symp. FAO/IAEA, Vienna, 1966.

Davidescu, D. and E. Davidescu. 1960a. Supplementary foliar application of nutrients to spring wheat. (Rm.r.f.). Luc. Stiint. Inst. Agron. "N.Balcescu" 4A: 95-102.

Davidescu, D. and E. Davidescu. 1960b. The efficiency of foliar application of mineral fertilizers to tomato. ORm.r.f.). Luc. Stiint. Inst. Agron. "N.Balcescu" 4A: 103-108.

De, R. 1971. An appraisal of aerial applications of urea solution for increasing the productivity of dry land wheat in the states of Madhya Pradesh, Rajasthan and Jammu and Kashina. World Soil Resources Reports No. 41: 226-227.

De Datta, S. K. and J. C. Moomaw. 1965. Availability of phosphorus to sugar cane in Hawaii as influenced by various phosphorus fertilizers and methods pf application. Exp. Agric. 1: 261-270.

deMooy, C. J. 1965. Differential responses of soybean varieties to application of phosphorus and potassium and calcium carbonate materials with respect to leaf composition and yield. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

deMooy, C. J. and J. Pesek. 1971. Response in yield and leaf composition of soybean varieties to phosphorus, potassium and calcium carbonate materials. Iowa State Univ. Res. Bull. 572.

deMooy, C. J., J. Pesek and E. Spaldon. 1973. Mineral nutrition of soybeans, p. 267-352. In B. E. Caldwell (ed.) Soybeans: Improvement, production and uses. ASA No. 16.

Dunphy, E. J. 1972. Soybean water-soluble carbohydrate, nutrient, yield and growth pattern responses to phosphorus and potassium fertility differences. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Eggert, R., L. T. Kardos and R. D. Smith. 1952. The relative absorption of phosphorus by apple trees and fruits from foliar sprays, and from soil applications of fertilizer, using radioactive phosphorus as a tracer. Proc. Amer. Soc. Hort. Sci. 60: 75-86.

Ellerton, H. D. and P. J. Dunlop. 1966. Activity coefficients for the systems water-urea and water-urea-sucrose at 25°C from isopiestic measurements. J. Phys. Chem. 70: 1831-1837.

Fehr, W. R., C. E. Caviness, D. T. Burmood and J. S. Pennington. 1971. Stage of development descriptions for soybeans, Glycine max (L.) Merrill. Crop Sci. 11: 929-931.

Ferencz, V. 1954. The effect of fertilizer sprays on wheat yields. (Hu. r.e.). Novenytermeles 3: 203-208.

Ferencz, V. 1963. Foliar application of fertilizers. (Hu.). Agrokem. Talajtan 12: 487-498.

Ferraz, C. A., M. G. Fuzatto, T. L. Guidi-Papp. 1969. Preliminary data on the foliar application of mineral nitrogen fertilizers to cotton. Bragantia 28: 33-38.

Fisher, E. G. and D. R. Walker. 1955. The apparent absorption of phosphorus and magnesium from sprays applied to the lower surface of McIntosh apple leaves. Proc. Amer. Soc. Hort. Sci. 65: 17-24.

Franke, W. 1967. Mechanisms of foliar penetration of solutions. Ann. Rev. Plant Physiol. 18: 281-300.

Fried, M. and R. E. Shapiro. 1961. Soil plant relationships in ion uptake. Ann. Rev. Plant Physiol. 12: 91-112.

Galgoczi, J. 1967. Two-year results on the spray fertilizing of sunflower on sandy soils in Szaboles county. (Hu.r.e.). Fiserl. Kozl. 58B: 71-80.

Gris, E. 1844. Nouvelles experiences sur l'action des composes ferrugineux solubles appliques a la vegetation et specialement au tratement de la chlorose et a la debilite des plantes. Compt. Rend. (Paris) 19: 1118-1119.

Haertl, E. G. 1955. New horizons in the application of chelation to agriculture. Down to Earth, Summer 1955: 6-9.

Hammond, L. C., C. A. Black and A. G. Norman. 1951. Nutrient uptake by soybeans on two Iowa soils. Iowa Agr. Exp. Sta. Res. Bull. 384.

Hanway, J. J. 1975. Interrelated developmental and biochemical processes in the growth of soybean plants. Proc. World Soybean Research Conference, University of Illinois.

Hanway, J. J. and H. E. Thompson. 1967. How a soybean plant develops. Iowa State Univ. Spec. Rept. 53.

Hanway, J. J. and C. R. Weber. 1971a. Accumulation of N, P, and K by soybean (Glycine max (L.) Merrill) plants. Agron. J. 63: 406-408.

Hanway, J. J. and C. R. Weber. 1971b. Dry matter accumulation in soybean (Glycine max (L.) Merrill) plants as influenced by N, P, and K fertilization. Agron. J. 63: 263-266.

Hanway, J. J. and C. R. Weber. 1971c. Dry matter accumulation in eight soybean (Glycine max (L.) Merrill) varieties. Agron. J. 63: 227-230.

Hanway, J. J. and C. R. Weber. 1971d. N, P, and K percentages in soybean (Glycine max (L.) Merrill) plant parts. Agron. J. 63: 286-290.

Harper, J. E. 1971. Seasonal nutrient uptake and accumulation patterns in soybeans. Crop Sci. 11: 347-350.

Henderson, J. B. and E. J. Kamprath. 1970. Nutrient and dry matter accumulation by soybeans. North Carolina Agr. Exp. Sta. Tech. Bull. 197.

Hicks, D. R. and J. W. Pendleton. 1969. Effect of floral bud removal on performance of soybeans. Crop Sci. 9: 435-437.

Hume, D. J. and J. G. Criswell. 1972. Translocation and respiration losses in soybeans after assimilation of $^{14}CO_2$ at various growth stages. Agron. Abstr. 35.

Jain, N. K., M. C. Agarwal. 1973. Effect of foliar spray of urea at different stages of tillering in wheat Sonora-64. Indian J. Agri. Res. 43: 12-17.

Kaindl, K. 1954. Foliar fertilization with phosphatic nutrients labeled with ^{32}P, p. 397. In J. E. Johnson (ed.) Radioisotopic Conference (1954). Medical and Physiological Applications, Vol. 1. Butterworth, London.

Kamprath, E. J. and E. V. Miller. 1958. Soybean yields as a function of soil phosphorus level. Soil Sci. Soc. Amer. Proc. 22: 317-319.

Khodzhaeva, N. A. 1961a. Effect of extra-root nutrition on accumulation of nutrient substances in strawberries. (In Russian). Dokl. S-kh. Akad. Timiryazeva 62: 209-216.

Khodzhaeva, N. A. 1961b. Dependence of strawberry yield on dates of extra-root top-dressing and plant age. (In Russian). Dokl. S-kh. Akad. Timiryazeva 62: 323-328.

Kick, H. and D. Hellwig. 1959. Vegetations versuche mit Helianthus annus zur quantitativen Aufnahme von N, P und K über das Blatt im Vergleich zur Aufnahme über die Wurzel. Z. Pflanzennernahr. Dung. Bodenk. 84: 265-271.

Klechkowski, V. M. 1956. The use of tracer atoms in studying the application of fertilizers. Int. Conf. Peaceful Uses of Atomic Energy (Geneva, 1955) 12: 109-117.

Koller, H. R. 1971. Analysis of growth within distinct strata of soybean community. Crop Sci. 11: 400-402.

Koontz, H. and O. Biddulph. 1957. Factors affecting absorption and translocation of foliar applied phosphorus. Plant Physiol. 32: 463-470.

Kovalik, A. E. 1969. The effect of foliar nutrition and its combination with growth substance treatment on the yield and physiological-biochemical processes in tomatoes. (In Russian). Tr. Khar'k. S-kh. Inst. 78(115): 15-19. Hort. Abstr. 40(4): 8620.

Kuthy, S. 1954. The effect of fertilizer sprays on lettuce and peas. (Hu.r.g.). Agrokem. Talajtan 3: 189-196.

Kuthy, S., V. Ferencz and L. Markus. 1952. The effect of fertilizer spray on sugar beet. (Hu.r.g.). Agrikem. Talajtan 1: 425-430.

Lang, A. L. and L. B. Miller. 1942. What about fertilizing soybeans? Ill. Ext. Serv. Leaflet, April 1942.

Lawn, R. J. and W. A. Brun. 1974. Symbiotic nitrogen fixation in soybeans. I. Effect of photosynthetic source-sink manipulations. Crop Sci. 14: 11-16.

Laties, G. C. 1959. Active transport of salt into plant time tissue. Ann. Rev. Plant Physiol. 10: 87-112.

Lingle, J. C. and D. M. Holmberg. 1956. Zinc deficient annual crops. Calif. Agri. 10: 13-14.

Linskens, H. F., W. Heinen and A. L. Stoppers. 1965. Cuticula of leaves and the residue problems. Residue Review 8: 136.

Madero Bernal, A. 1953. A new system for fertilizing in cacao cultivation. Cacao en Colombia 2: 77-89. Z. Pflanzenernahr. Dung. Bodenk. 85: 275.

Mathus, B. S., P. S. Bhatnagar and S. Singh. 1969. Foliar and soil applications of nitrogen to wheat. Trop. Agric. Trin. 46: 255-259.

McNall, L. R. and G. B. Hinckley. 1973. Foliar feeding increases almond yield. Western Fruit Grower 27(3): 8.

Mederski, H. J. and G. W. Volk. 1956. Foliar fertilization of field crops. Ohio Agric. Exp. Sta. Res. Circ. 35.

Mednis, Y. A. 1952. Top-dressing of plants other than through the roots. (In Russian). Sov. Agron. 7: 53-61.

Mel'nichuk, P. P. 1960. The nutrition of vegetable and fruit crops through the leaves. (In Russian). Sb. Nauchn. Tr. Uman. S-kh. Inst. 12: 207-124.

Melsted, S. W. 1967. The philosophy of soil testing, p. 13-24. In Soil testing and plant analysis, Part I. Soil Sci. Soc. Amer. Spec. Publ. 2, Madison, Wisconsin.

Metzger, J. E., M. G. Holmer and H. Bierman. 1925. Soybeans: production, composition and feeding value. Md. Agr. Exp. Sta. Bull. 277.

Mihajlova, L. P. 1970. On the problem of the phytotoxicity of nematocides. (In Russian). Himija Sel'. Hoz. 8(6): 37-39. Hort. Abstr. 41(2): 42500.

Milica, C. I. 1959. Contribution to the problem of the supplementary extra-root nutrition of sugar beet. (Rm.r.f.). An. Inst. Cerc. Agron. Roman. 26: 21-43.

Miller, R. J. 1960. Soybean yield responses and plant composition as affected by P and K fertilizers. Ph.D. dissertation. Library, Iowa State University, Ames, Iowa.

Miller, R. J., J. T. Pesek and J. J. Hanway. 1961. Soybean yield responses to fertilizers. Soybean Digest 21(5): 6-8.

Milojic, B. 1957. A contribution to the study of foliar absorption of nutrients by the sugar beet. (Sb.e.). Zborn. Rad. poljopr. Fak. Univ. Beograd 5: 85-92.

Mostert, M. and C. Sonneveld. 1964. Foliar application of nutrients. (In Dutch). Jversl. Proefstat. Groen. Fruit. Glas, Naaldwijk. 1965: 39-41. Hort. Abstr. 36(2): 2826.

Moustafa, E., M. Boland and R. M. Greenwood. 1971. Transport of phosphate from leaves to leguminous root nodules. Plant Soil 35: 651-653.

Mukherjee, S. K., R. De and P. N. Saxena. 1966. Efficiency of utilization of soil- and foliar-applied nitrogen and phosphorus as revealed by tuber production and nutrient uptake of potatoes. Soil Sci. 102: 278-283.

Nagymihaly, F., E. Leszek and C. Rotko. 1954. The effect of fertilizer spray on sugarbeet. II. (Hu.r.g.). Agrokem. Talajtan 3: 197-204.

Narayanan, T. R. and K. V. Vasudevan. 1957. Foliar versus soil fertilizer and application in crops. Madras Agric. J. 44: 663.

Narayanan, T. R. and V. Vasudevan. 1959. Studies on foliar nutrition of crops: III. Ragi and maize. Madras Agric. J. 46: 223-229.

Natali, S. and F. Zucconi. 1968. Foliar fertilizing of non-irrigated grape vine under an arid warm climate. (In Italian). Ital. Agric. 105: 342-350. Hort. Abstr. 38(4): 7308.

Nelson, W. L. 1946. Fertilizing soybeans: lime, potash and phosphates are needed. North Carolina Res. Farm. 4(3): 4-5, 9.

Nelson, W. L., L. Burkhart and W. E. Colwell. 1945. Fruit development, seed quality, chemical composition and yield of soybeans as affected by potassium and magnesium. Soil Sci. Soc. Amer. Proc. 10: 224-229.

Nerson, H. and Z. Karchi. 1972. A comparative study of soil versus foliar application of NH_4NO_3 to wheat under different moisture regimes. Israel J. Agri. Res. 22(3): 171-177.

Okuda, A. and Y. Yamada. 1962. Foliar absorption of nutrients: IV. The effect of some organic compounds on the absorption of foliar applied phosphoric acid. Soil Sci. Plant Nutri. 8: 147-149.

Pallas, J. E., Jr. and G. G. Williams. 1962. Foliar absorption and translocation of P^{32} and 2,4-dichlorophenoxyacetic acid as affected by soil-moisture tension. Bot. Gaz. 123: 175-180.

Pavlov, A. N. and V. P. Ivanov. 1960. Extra-root topdressing of maize with nitrogen and phosphorus at different levels of root nutrition. (R.e.). Fiziol. Rast. 7: 564-570.

Pecznik, J. and G. Merei. 1962. Results of large-scale foliar spraying of grape vine. (Hu.r.e.). Agrartud. Egypt. mezogazd. Kar. Kozl. 1962: 319-332.

Pendleton, J. W. 1968. Soybean fertility studies. III. Iowa State University Agron Dept. Publication AG-1945.

Peterson. V. H. 1961. Raising the fertility level increases soybean yields. Soybean Digest 21(5): 9.

Pierre, W. H. 1944. Soil fertility factors affecting soybean yield. Soybean Digest 4(6): 12-13.

Polgar, S. 1962. Experimental results on the foliar spraying of rice. (Hu.r.e.). Kiserl. Kozlem. 55A(2): 43-57.

Roldan, R. J., L. H. Meyer and R. A. Luse. 1968. Effect of wetting agents upon uptake by sugarcane of foliar-applied phosphorus. J. Agric. Univ. P.R. 52: 38-46.

Rozhanovskii, S. 1956. Extra-root nutrition of autumn-sown wheat. (Azerb.r.). Sots Sel'sk. Khoz. Azerb. 2: 61-63.

Sato, K., M. Ishihara and R. Harada. 1954. Studies on the foliar sprays of phosphate in fruit trees (1). J. Hort. Assoc. Japan 23: 159-164.

Shtrausberg, D. V. 1958. The assimilation of nutritive elements by plants in the polar region under various temperature conditions. Plant Physiol. (USSR) (English Transl.) 5: 226-231.

Shukla, G. C. 1974. Soil and foliar fertilization of phosphorus on yield and protein content of soybeans. Technology, India 11(1): 70-72.

Shumacher, K. N. and L. F. Welch. 1970. Foliar application of N and P to corn and soybeans. Agron. Abstr. 1970: 127.

Sinclair, T. R. and C. T. de Wit. 1975. Photosynthate and nitrogen requirements for seed production by various crops. Science 189: 565-569.

Singh, R. and D. S. Bains. 1973. Effects of different levels, times, and methods of application of urea on the yield and quality of barley. Indian J. Agri. Sci. 43: 727-730.

Singh, H. G. and M. S. Sarolia. 1970. Note on the time and methods of urea application to maize grown on soils with undulating topography. Indian J. Agric. Sci. 40: 470-473.

Sita Ram, M. S. and E. S. Abraham. 1970. Effect of foliar application of fertilizers on the fiber quality of 'Laxmi' cotton. Indian J. Agric. Sci. 40: 772-775.

Srinivasan, K. M. 1961. Observations on the foliar absorption of P^{32} in bean plants as influenced by light. South Indian Hort. 9: 20-23.

Suleimanov, I. C. 1956. On the question of non-root plant nutrition by phosphorus. (In Russian). Uch. Zap. Kazan. Univ. 116: 212-216. Referat Zhur. Biol. 1957 No. 22489.

Tabatabai, M. A. and J. M. Bremner. 1971. A simple turbidimetric method of determining total sulfur in plant materials. Agron. J. 62: 805-806.

Teubner, F. G., S. H. Wittwer, W. G. Long and H. B. Tukey. 1957. Some factors affecting absorption and transport of foliar applied nutrients. Mich. Agric. Exp. Sta. Q. Bull. 39: 398-415.

Thaine, R., S. L. Ovenden and J. S. Turner. 1959. Translocation of labelled assimilates in the soybean. Aust. J. Biol. Sci. 12: 349-372.

Thibodeau, P. S. and E. G. Jaworski. Patterns of nitrogen utilization in the soybean. Planta 127: 133-147.

Thomas, W. 1960. The effect of foliar applied nitrogen, phosphorus, and potassium on the growth and composition of corn. Diss. Abstr. 20: 2477.

Thorne, G. N. 1955a. Interactions of nitrogen, phosphorus and potassium supplied in leaf sprays or in fertilizer added to the soil. J. Exp. Bot. 6: 20-42.

Thorne, G. N. 1955b. Nutrient uptake from leaf sprays by crops. Field Crop Abstr. 8: 147-152.

Thorne, G. N. 1958. Factors affecting uptake of radioactive phosphorus by leaves and its translocation to other parts of the plant. Ann. Bot. 22: 381-398.

Thrower, S. L. 1962. Translocation of labelled assimilates in soybean. 2. The pattern of translocation in intact and defoliated plants. Aust. J. Biol. Sci. 15: 629-649.

Thrower, S. L. 1965. Translocation of labelled assimilates in the soybean. 4. Some effects of low temperature on translocation. Aust. J. Biol. Sci. 18: 449-461.

Tukey, H. B., S. H. Wittwer, F. G. Teubner and W. G. Long. 1956. Utilization of radioactive isotopes in resolving the effectiveness of foliar absorption of plant nutrients. Proc. Int. Conf. Peaceful Uses Atomic Energy 12: 138-143. United Nations, New York.

Tukey, H. B., S. H. Wittwer and M. J. Bukovac. 1961. Absorption of radionuclides by above-ground plant parts and movement within the plant. J. Agric. Food Chem. 9: 106-113.

University of Illinois. 1961. Illinois Agronomy handbook, 1969. Univ. of Illinois, Dept. of Agronomy, Urbana, Illinois.

Ursulenko, P. K. 1958. Use of labeled phosphorus in the study of foliar nutrition of fruit-bearing plants. In Fiziol. Rast. Agrokhimiya. Pochvovedenie. Akad. Nauk. SSSR: Moscow. Biol. Abstr. 47(24): 119017.

Uturgauri, A. I. and O. G. Oniani. 1963. Foliar intake of radioactive phosphorus by tea plants. (R.e.). Subrop. Kul't. 1: 23-30. Biol. Abstr. 45(18): 79705.

Van Overbeek, J. and R. Bloudeau. 1954. Mode of action of phytotoxic oils. Weeds 3: 55-65.

Verma, S. S. and V. M. Sahni. 1963. Effect of foliar applications of nutrients on the yield of cotton. Indian Cotton Grow. Rev. 17: 247-248.

Vertil, S. A. and N. C. Malyuga. 1970. Effect of nitrogen top-dressing on yield and quality of winter wheat receiving different fertilizer treatments. Agrokhimiya 2: 3-13.

Vittum, M. T. and R. R. Mulvey. 1944. More about soybean fertilization. Better Crops with Plant Food 28(5): 6-10.

Vogl, M. 1960. Blättdungung bei Fichten mit radiophosphor. Arch. Forstw. 9: 1125-1139.

Von Boguslawski, E. and A. Vomel. 1957. Foliar fertilizing of oats with single nutrients and complete fertilizer. (In German). Landwirtsch. Forsch. Sonderh. 9: 83-94.

Vonka, Z. and V. Bezdek. 1974. The effect of urea sprays on yield and or grain protein accumulation in spring barley. Soils and Fertilizers Vol. 37(10): 309.

Walker, W. M. and D. H. Long. 1966. Effect of selected soil fertility parameters on soybean yields. Agron. J. 58: 403-405.

Winter, H. and D. C. Martimer. 1967. Role of the root in the translocation of products of photosynthesis in sugar beet, soybean and pumpkin. Can. J. Bot. 45: 1811-1822.

Wittwer, S. H. 1951. Use of fertilizer solutions in leaf feeding. Proc. National Joint Committee on Fertilizer Application 1951: 46-47.

Wittwer, S. H. 1964. Foliar absorption of plant nutrients. Adv. Frontiers Plant Sci. 8: 161-182.

Wittwer, S. H. and W. S. Lundahl. 1951. Autoradiographic as an aid in determining the gross absorption and utilization of foliar applied nutrients. Plant Physiol. 26: 792-797.

Wittwer, S. H., M. J. Bukovac and H. B. Tukey. 1963. Advances in foliar feeding of plant nutrients. In M. H. McVickar, G. L. Bridger and L. B. Nelson (eds.) Fertilizer technology and usage. Soil Sci. Soc. Amer. Madison, Wisconsin.

Wittwer, S. H., W. H. Jung, Y. Yamada, M. J. Bukovac, R. De, S. Kannan, H. P. Rasmussen and S. N. Haile Mariam. 1965. Pathways and mechanisms for foliar absorption of mineral nutrients as revealed by radioisotopes. In Isotopes and radiation in soil-plant nutrition studies. Proc. Symp. FAO/IAEA, Ankara 1965: 387-401.

Yamada, Y., M. J. Bukovac and S. H. Wittwer. 1964a. Ion binding by surfaces of isolated cuticular membranes. Plant Physiol. 39: 978-982.

Yamada, Y., S. H. Wittwer and M. J. Bukovac. 1964b. Penetration of ions through isolated cuticles. Plant Physiol. 39: 28-32.

Yamada, Y., W. H. Yung, S. H. Wittwer and M. J. Bukovac. 1965. The effects of urea on ion penetration through isolated cuticular membranes and ion uptake by cells. Proc. Amer. Soc. Hort. Sci. 87: 429-432.

Yatazawa, M. and S. Higashimo. 1952. Studies on the foliar application of nutrient elements. I. The absorption of $KH_2P^{32}O_4$ through the leaf epidermis. (J.e.). J. Sci. Soil Man. (Japan) 22: 191-192.

Yatazawa, M. and S. Higashimo. 1953. The mechanism of the foliar absorption of phosphate. II. Forms of transferring phosphate after the foliar absorption. (J.e.). J. Sci. Soil Man. (Japan) 24: 193-196.

Yeh, Y. Y. 1967. Phosphorus uptake by foliar application on leafy vegetable crops. J. Agric. Assoc. China 60: 43-54.

Yung, J. and S. H. Wittwer. 1963. Kinetics of foliar absorption. Proc. Plant Physiol. Meeting, Amherst, Mass., 38: 26.

Zhurbitzky, Z. I. and D. V. Shtrausberg. 1958. The effect of temperature on the mineral nutrition of plants. Proc. First (UNESCO) Int. Conf. Radioisotopes Sci. Res. 4: 270-285.

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X. APPENDIX

Table 44. Soybean yields, 1974

Treatment N-P-K-S	Rep	Yield (kg/ha) Time of application R4-5	R5-6	R6-6.5
Check	1	2276	2223	2223
	2	2302	2328	2250
34-0-0-0	1	2380	2537	2380
	2	2459	2459	2407
34-0-0-0+150[a]	1	2616	2590	2354
	2	2694	2564	2459
7-21.4-36-0	1	2433	2564	2485
	2	2407	2485	2250
41-21.4-36-0-150[a]	1	2407	2616	2433
	2	2328	2642	2485
49-21.4-36-9-150[a]	1	2380	2799	2799
	2	2354	2694	2747

[a]150 kg/ha of sucrose.

Table 45. Effect on soybean yields and seed size of foliar fertilization of soybeans, factorial experiment 1975

Trt. no.	Amount of nutrient applied (kg/ha) N	P	K	S	Rep	Yield ton/ha	Weight/ 100 seeds (g)
1	120	12	36	6	1	3.162	16.27
					2	3.223	15.62
					3	3,287	16.04
2	120	12	36	2	1	3.280	15.82
					2	3.241	15.43
					3	2.912	15.72
3	120	12	12	6	1	3.446	16.64
					2	3.355	15.96
					3	3.130	15.47
4	120	12	12	2	1	3.637	16.27
					2	3.222	15.59
					3	3.170	14.53
5	120	4	36	6	1	3.003	15.43
					2	2.920	14.99
					3	2.921	15.15
6	120	4	36	2	1	2.980	15.79
					2	2.604	15.92
					3	2.991	16.01
7	120	4	12	6	1	2.998	16.10
					2	3.121	15.60
					3	2.945	15.93
8	120	4	12	2	1	3.069	16.46
					2	3.191	15.10
					3	2.643	15.79
9	40	12	36	6	1	2.962	16.91
					2	3.025	15.47
					3	3.078	15.97
10	40	12	36	2	1	2.912	15.84
					2	2.912	15.56
					3	3.041	15.39

Table 45. (Continued)

Trt. no.	Amount of nutrient applied (kg/ha) N	P	K	S	Rep	Yield ton/ha	Weight/ 100 seeds (g)
11	40	12	12	6	1	3.196	15.98
					2	3.219	15.71
					3	2.388	15.88
12	40	12	12	2	1	3.355	17.12
					2	3.321	16.00
					3	3.276	15.65
13	40	4	36	6	1	3.355	16.74
					2	3.493	15.94
					3	3.210	15.50
14	40	4	36	6	1	3.359	15.22
					2	3.560	15.10
					3	3.275	15.49
15	40	4	12	6	1	3.025	14.81
					2	3.018	15.46
					3	2.547	15.28
16	40	4	12	2	1	3.153	16.19
					2	3.116	15.98
					3	2.730	16.68
17	160	8	24	4	1	2.998	16.24
					2	2.980	15.68
					3	2.980	15.46
18	80	16	24	4	1	3.617	16.44
					2	3.446	15.90
					3	3.801	16.44
19	80	8	48	4	1	3.116	16.01
					2	3.013	15.64
					3	3.128	15.39
20	80	8	24	8	1	4.373	16.04
					2	3.832	16.77
					3	3.867	16.01

Table 45. (Continued)

Trt. no.	Amount of nutrient applied (kg/ha) N	P	K	S	Rep	Yield ton/ha	Weight/ 100 seeds (g)
21	0	8	24	4	1	2.968	16.23
					2	2.650	15.23
					3	2.809	15.72
22	80	0	24	4	1	3.175	15.54
					2	2.235	15.44
					3	2.866	16.85
23	80	8	0	4	1	2.732	15.72
					2	2.900	16.32
					3	2.882	15.17
24	80	8	24	0	1	3.144	16.75
					2	3.401	16.63
					3	3.333	16.60
25	80	8	24	4	1	3.437	16.52
					2	3.605	16.00
					3	3.605	16.05
26	0	0	0	0	1	2.991	15.73
					2	2.907	16.55
					3	3.048	15.75

Table 46. Treatment combinations, yield, N, P, K and protein content in leaves and beans at different stages of development, factorial experiment 1975

Trt. no.	Amount of nutrients applied, kg/ha N - P - K - S	Yield bu/ha	Leaves R5.5 % N	% P	% K	Leaves R6 % N	% P	% K
1	120-12-36-6	3.224	3.11	0.237	0.896	2.66	0.221	0.756
2	120-12-36-2	3.144	3.26	0.238	0.820	2.67	0.260	0.715
3	120-12-12-6	3.310	3.27	0.241	0.873	2.89	0.245	0.636
4	120-12-12-2	3.343	3.30	0.267	0.828	2.77	0.263	0.631
5	120- 4-36-6	2.948	3.07	0.199	0.830	2.48	0.186	0.646
6	120- 4-36-2	2.858	2.30	0.224	0.813	2.58	0.190	0.620
7	120- 4-12-6	3.021	3.18	0.195	0.870	2.52	0.222	1.133
8	120- 4-12-2	2.967	3.15	0.230	1.273	2.75	0.217	0.966
9	40- 8-36-6	3.021	3.18	0.220	0.750	2.79	0.231	0.733
10	40-12-36-2	2.955	3.09	0.242	0.906	2.73	0.234	0.806
11	40-12-12-6	2.934	3.24	0.239	0.926	2.94	0.241	0.800
12	40-12-12-2	3.250	3.24	0.226	0.772	2.51	0.222	0.700
13	40- 4-36-6	3.352	3.15	0.210	0.728	2.70	0.214	0.680
14	40- 4-36-2	3.398	3.31	0.230	0.931	2.72	0.197	0.700
15	40- 4-12-6	2.863	3.67	0.287	0.960	2.77	0.236	0.636
16	40- 4-12-2	2.999	3.29	0.230	0.800	2.70	0.193	0.570
17	160- 8-24-4	2.960	3.55	0.255	0.933	2.82	0.217	0.613
18	80-16-24-4	3.621	3.23	0.305	0.883	2.52	0.281	0.650
19	80- 8-48-4	3.085	3.58	0.278	0.913	2.84	0.271	0.686
20	80- 8-24-8	4.024	3.38	0.264	0.935	2.84	0.267	0.906
21	0- 8-24-4	2.809	3.23	0.311	0.926	2.05	0.258	0.826
22	80- 0-24-4	3.092	3.37	0.223	0.860	2.84	0.181	0.916
23	80- 8- 0-4	2.838	2.77	0.219	0.683	2.40	0.236	0.768
24	80- 8-24-0	3.292	3.20	0.290	0.936	2.76	0.267	0.903
25	80- 8-24-4	3.549	3.55	0.266	0.875	2.66	0.238	0.733
26	0- 0- 0-0	2.982	2.87	0.185	0.753	2.17	0.138	0.620

Leaves R6.5			Beans - harvested				Weight/ 100 seeds (g)	Oil %
% N	% P	% K	% N	% protein	% P	% K		
2.42	0.267	0.630	6.47	38.25	0.507	1.963	15.97	
2.36	0.297	0.693	6.62	40.94	0.504	2.020	15.65	
2.35	0.258	0.490	6.70	42.00	0.497	1.983	16.02	
2.70	0.315	0.651	6.92	43.50	0.490	1.876	15.46	20.1
2.31	0.167	0.563	6.78	41.19	0.488	2.033	15.19	20.7
2.52	0.216	0.560	7.12	45.25	0.504	2.023	15.96	
2.42	0.189	0.653	6.89	42.88	0.506	2.040	15.87	
2.50	0.234	0.690	6.88	43.00	0.518	2.063	15.78	
2.16	0.272	0.573	6.71	42.45	0.526	2.060	16.11	
2.29	0.268	0.693	6.58	41.38	0.545	2.066	15.59	
2.45	0.296	0.546	6.79	43.00	0.561	2.063	15.85	
2.19	0.215	2.460	6.79	44.56	0.539	2.023	16.25	21.4
2.15	0.230	0.700	6.60	43.44	0.527	2.053	16.06	21.6
2.64	0.270	0.763	6.51	41.75	0.507	2.003	15.27	
2.63	0.292	0.666	6.82	43.75	0.513	2.026	15.18	
2.90	0.311	0.646	6.41	39.81	0.508	2.006	16.28	
2.93	0.247	0.740	6.75	42.19	0.491	1.983	15.79	20.6
2.45	0.329	0.680	6.72	41.88	0.526	2.010	16.26	20.6
2.85	0.274	0.610	6.66	42.00	0.505	2.023	15.74	
2.44	0.272	0.710	6.80	42.50	0.518	1.986	16.27	20.8
2.53	0.316	0.800	6.24	39.69	0.545	2.033	15.72	22.1
2.77	0.249	0.700	6.70	42.25	0.511	2.013	15.94	20.9
2.40	0.260	0.550	6.73	41.75	0.488	1.976	15.73	21.0
2.55	0.262	0.613	6.60	40.94	0.510	2.026	16.66	21.2
2.69	0.206	0.763	6.67	41.50	0.530	1.976	16.19	20.7
1.51	0.154	0.676	6.29	38.56	0.522	1.976	15.81	22.0

Table 47. Correlation matrix between variables[a], factorial experiment 1975

		Yield bu/ha	Leaves R5.5 % N	Leaves R5.5 % P	Leaves R5.5 % K	Leaves R6 % N	Leaves R6 % P	Leaves R6 % K
Amount of nutrients applied, kg/ha	N	0.079	0.125	-0.053	0.205	0.244	0.121	0.007
		0.50	0.53	0.65	0.07	0.03	0.29	0.98
	P	0.070	0.026	0.427	-0.039	0.075	0.575	-0.064
		0.01	0.81	0.0002	0.74	0.52	0.0001	0.59
	K	0.121	0.214	0.127	0.009	0.169	0.131	-0.018
		0.29	0.06	0.27	0.93	0.13	0.25	0.87
	S	0.181	0.148	0.003	0.004	0.181	0.184	0.175
		0.11	0.19	0.78	0.97	0.11	0.10	0.13
Yield, ton/ha		1.0	0.106	0.154	-0.020	0.173	0.309	0.168
		0.0	0.04	0.18	0.56	0.13	0.01	0.14
Leaves R5.5	% N		1.00	0.030	0.200	0.308	0.145	-0.079
			0.0001	0.08	0.006	0.20	0.50	0.0001
	% P			0.00	0.304	0.120	0.573	-0.005
				0.0	0.02	0.29	0.0001	0.96
	% K				1.00	0.186	0.152	0.181
					0.0	0.10	0.15	0.11
Leaves R6	% N					1.00	0.319	0.208
						0.0	0.00	0.07
	% P						1.00	0.390
							0.0	0.0006
	% K							1.00
								0.0
Leaves R6.5	% N							
	% P							
	% K							
Beans, harvested	% N							
	% protein							
	% P							
	% K							
Wt/100 seeds, g								

[a]The number below each correlation coefficient shows the probability > R under the null hypothesis R = 0, N = 78.

Leaves R6.5			Beans, harvested				Wt/100 seeds, g
% N	% P	% K	% N	% protein	% P	% K	
0.288	-0.083	-0.095	0.445	0.446	-0.380	-0.132	-0.035
0.01	0.52	0.59	0.0002	0.0002	0.0009	0.25	0.78
0.034	0.395	-0.127	0.373	0.040	0.142	-0.083	0.083
0.77	0.0006	0.27	0.75	0.73	0.21	0.52	0.53
0.159	0.0.71	0.124	-0.013	-0.013	-0.008	0.102	-0.057
0.16	0.55	0.28	0.91	0.91	0.95	0.29	0.62
0.026	0.049	-0.027	0.152	0.158	0.101	0.052	-0.042
0.82	0.67	0.21	0.18	0.163	0.93	0.65	0.72
0.064	0.070	0.89	0.042	0.045	-0.094	-0.022	0.248
0.58	0.551	0.55	0.71	0.69	0.58	0.84	0.03
0.414	0.096	0.114	0.149	0.146	0.025	-0.078	0.072
0.0001	0.59	0.31	0.19	0.20	0.83	0.50	0.54
0.312	0.482	0.196	-0.084	-0.051	0.132	-0.024	0.177
0.01	0.001	0.08	0.53	0.54	0.25	0.83	0.12
0.176	0.074	0.151	0.137	0.135	0.164	0.349	0.106
0.12	0.61	0.18	0.23	0.24	0.63	0.0006	0.64
0.243	0.181	-0.065	0.205	0.206	-0.183	0.046	0.103
0.03	0.11	0.581	0.07	0.07	0.11	0.67	0.63
0.285	0.510	0.145	0.149	0.160	0.091	0.083	0.115
0.01	0.0001	0.20	0.19	0.186	0.57	0.52	0.32
-0.024	-0.025	0.251	0.031	0.034	-0.057	0.280	0.200
0.830	0.822	0.03	0.78	0.76	0.63	0.01	0.08
1.00	0.508	0.293	0.141	0.139	-0.180	-0.110	-0.311
0.0	0.0001	0.02	0.22	0.22	0.26	0.26	0.78
	1.00	0.217	-0.138	-0.137	-0.010	-0.135	0.024
	0.0	0.05	0.23	0.23	0.93	0.24	0.83
		1.00	-0.191	-0.191	-0.021	0.126	0.104
		0.0	0.09	0.09	0.85	0.27	0.63
			1.00	0.999	0.006	0.230	-0.027
			0.0	0.0001	0.96	0.04	0.81
			1	1.00	0.009	0.234	-0.018
				0.0	0.94	0.037	0.87
					1.0	0.263	0.118
					0.0	0.02	0.30
						1.00	0.201
						0.0 0.0	0.07
							1.0
							0.0

Table 48. Treatments, yields and nutrient content of leaves and beans, time of application experiment, Ames 1975

Trt.	Rep.	Yield ton/ha	Leaves R5 % N	Leaves R5 % P	Leaves R5 % K	Leaves R5.5 % N	Leaves R5.5 % P	Leaves R5.5 % K
1-A	1	3402	3.70	.236	1.40	3.74	.296	1.200
	2	3495	3.83	.245	1.25	3.67	.328	1.200
	3	3620	3.83	.245	1.20	3.67	.328	1.200
2-A	1	2596	4.02	.250	1.40	3.81	.347	1.350
	2	2948	3.60	.250	1.20	3.62	.330	1.250
	3	2733	3.90	.250	1.25	4.20	.452	1.500
3-A	1	2937	3.86	.257	1.36	2.87	.209	1.010
	2	2334	3.67	.224	1.20	2.82	.192	0.975
	3	2789	3.71	.244	1.27	2.96	.202	1.210
4-A	1	2755	4.02	.338	1.46	3.34	.321	1.300
	2	2960	3.95	.320	1.58	3.33	.334	1.400
	3	3142	3.87	.335	1.49	3.78	.347	1.600
5-A	1	3190	4.40	.298	1.25	3.32	.273	1.200
	2	3177	4.02	.277	1.40	3.30	.240	1.250
	3	3313	3.92	.277	1.35	3.70	.290	1.100
6-A	1	2843	3.86	.241	1.36	2.87	.209	1.010
	2	2966	3.67	.244	1.20	2.82	.192	0.975
	3	2984	3.71	.244	1.27	2.96	.202	1.210

Leaves R6			Leaves R6.5			Beans - harvested			
% N	% P	% K	% N	% P	% K	% N	% P	% K	% prot.
3.47	.290	1.15	2.91	.328	0.960	6.70	.602	1.94	41.87
3.26	.295	1.20	2.52	.298	1.040	6.05	.518	1.85	37.81
3.53	.370	1.25	2.81	.280	0.960	6.59	.526	1.94	41.19
3.33	.350	1.40	1.86	.156	0.730	6.45	.542	2.02	40.31
3.24	.321	1.40	1.80	.160	0.810	5.78	.528	2.00	36.13
3.64	.461	1.50	2.01	.191	0.830	6.27	.546	1.93	39.19
3.36	.225	0.95	2.81	.331	1.080	5.75	.514	1.97	35.94
2.67	.186	0.75	2.49	.320	0.950	6.50	.549	1.97	40.63
2.75	.186	0.90	2.63	.247	0.820	6.82	.543	1.98	42.63
3.01	.334	1.16	2.25	.321	1.180	5.70	.511	1.95	35.63
2.98	.252	1.01	2.74	.302	1.180	6.69	.523	1.93	41.81
2.41	.212	0.95	2.73	.321	1.260	6.66	.546	1.95	41.63
3.45	.286	1.28	2.77	.329	0.900	6.21	.507	1.92	38.81
3.44	.292	1.19	2.18	.314	1.000	6.59	.496	1.91	41.19
3.78	.327	1.24	2.36	.247	0.900	6.61	.546	1.94	41.31
2.83	.192	1.20	1.76	.147	0.717	5.88	.565	1.92	36.75
2.70	.199	1.20	1.97	.169	0.893	5.99	.531	1.94	37.44
2.83	.210	1.16	2.02	.166	0.747	6.19	.536	1.93	38.69

Table 49. Treatments, yields and nutrient content of leaves and beans, time of application experiment, Kanawha 1975

Trt.	Rep	Yield ton/ha	Leaves R5 % N	Leaves R5 % P	Leaves R5 % K	Leaves R5.5 % N	Leaves R5.5 % P	Leaves R5.5 % K
1-K	1	3036	4.45	.348	1.14	3.78	.329	0.730
	2	2881	4.64	.324	0.99	3.34	.236	0.740
	3	2892	5.01	.340	0.95	3.91	.329	0.860
2-K	1	2649	4.51	.246	1.18	4.90	.454	1.000
	2	2429	4.72	.371	1.20	4.01	.481	1.240
	3	2478	4.56	.350	1.15	4.00	.516	0.840
3-K	1	2528	4.16	.213	1.05	3.49	.274	0.720
	2	2654	4.10	.309	1.00	3.26	.260	0.803
	3	2484	4.12	.320	1.02	3.41	.242	1.010
4-K	1	2528	4.75	.345	1.01	4.02	.449	0.920
	2	2872	4.45	.345	1.17	3.84	.463	1.310
	3	2484	4.21	.328	1.26	4.22	.424	1.280
6-K	1	2705	4.16	.313	1.05	3.46	.274	0.720
	2	2542	4.16	.313	1.05	3.26	.260	0.803
	3	2409	4.16	.213	1.05	3.41	.242	1.010

Leaves R6			Leaves R6.5			Beans- harvested			
% N	% P	% K	% N	% P	% K	% N	% P	% K	% prot.
3.87	.458	0.92	3.08	.465	0.880	7.24	.489	1.87	45.31
4.08	.434	1.32	3.43	.407	0.900	7.28	.586	1.85	45.50
3.99	.485	1.15	3.43	.407	0.900	7.27	.572	1.87	45.44
4.40	.531	1.04	2.56	.186	0.670	7.78	.596	1.88	48.63
4.21	.349	1.23	2.60	.190	0.610	7.80	.591	1.91	48.75
4.18	.531	1.34	2.41	.183	0.590	7.81	.572	1.89	48.81
2.58	.222	0.55	2.40	.237	0.860	7.60	.589	1.92	47.50
2.73	.255	0.68	2.87	.302	0.750	7.74	.596	1.91	48.38
2.70	.229	0.75	3.11	.323	1.060	7.02	.612	1.93	43.88
3.89	.500	1.12	3.44	.420	1.140	7.34	.631	1.99	45.88
3.56	.581	0.98	3.10	.354	1.370	7.33	.622	1.98	45.81
3.90	.489	1.06	3.59	.389	1.190	7.72	.612	1.97	48.25
2.68	.222	0.55	1.88	.136	0.307	7.05	.607	1.91	44.06
2.73	.255	0.68	1.86	.167	0.443	6.99	.612	1.89	43.69
2.20	.229	0.76	2.52	.181	0.620	7.05	.585	1.89	44.06

Table 50. Effect of foliar application on soybean yields of different cultivars with different dates of planting, Sutherland 1975

Total foliar application (kg/ha) N - P - K - S	Cultivar	Planting date	Rep	Yield, ton/ha Sprayed	Yield, ton/ha Not sprayed	No. of apps
240-24-72-12	Corsoy	May 22	1	3.204	3.868	8
			2	2.969	3.047	
			3	3.438	3.868	
240-24-72-12	Steele	May 22	1	3.555	3.868	8
			2	2.930	2.852	
			3	2.852	3.204	
120-12-36- 6	Clay	May 22	1	2.579	1.758	4
			2	1.406	1.289	
			3	2.383	1.993	
240-24-72-12	Corsoy	June 13	1	3.438	2.735	8
			2	2.383	3.360	
			3	2.852	2.813	
120-21-63-10.5	Steele	June 13	1	3.008	3.126	7
			2	2.930	2.852	
			3	2.852	2.930	
180-18-54- 9	Clay	June 13	1	1.993	2.618	6
			2	1.641	1.875	
			3	1.875	2.071	

Table 51. Effect of foliar fertilizer application between plant developmental stages R5 and R7 on yields of two soybean cultivars, Ames 1975

Soybean cultivar	Yield, ton/ha		Rep	Seed size, g/100 seeds	
	Not sprayed	Sprayed[a]		Not sprayed	Sprayed
Corsoy	3.576	5.197	1	14.8	15.5
	3.505	5.030	2	15.5	16.2
Amsoy	3.743	5.841	1	16.7	15.8
	3.957	4.840	2	16.7	16.3